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An Evaluation of Formaldehyde Problems in Residential Mobile Homes

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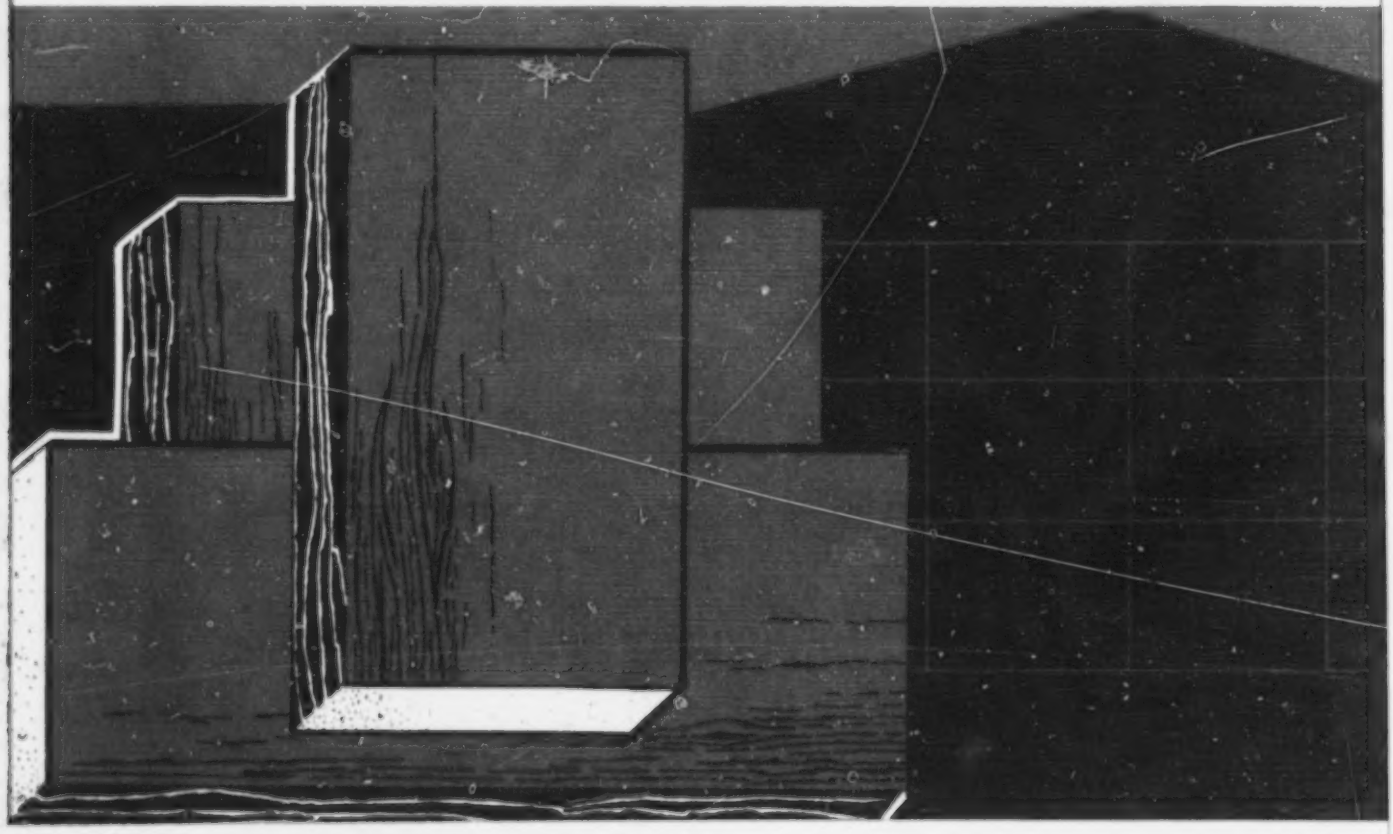

AN EVALUATION OF FORMALDEHYDE PROBLEMS IN RESIDENTIAL MOBILE HOMES

Prepared by

Geomet, Incorporated
and
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Final Task I Report

Contract H-5105

April, 1980

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The contents of this report do not necessarily reflect the views or policies of the U. S. Department of Housing and Urban Development or the United States Government.

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EXECUTIVE SUMMARY

At issue is whether the growing number of complaints by mobile-home occupants regarding elevated formaldehyde levels does indeed represent a health risk or is only perceived as such. Two related and practical concerns are: (1) an indoor formaldehyde concentration that may be suggested as an adequate safety standard; and (2) if the present state of scientific capability can reduce the mobile home formaldehyde concentrations to that standard level.

GEOMET, Incorporated, as a subcontractor to Technology + Economics, Inc. (T+E), addressed these concerns through review and interpretation of the available literature and empirical data. Specific areas researched included the relevant physical and chemical properties of formaldehyde, monitoring techniques, source identification, and formaldehyde emission strengths as they pertain to the mobile-home environment, observed formaldehyde levels, health effects, formaldehyde standards, and abatement techniques. Furthermore, the magnitude of the formaldehyde problem, based on T+E's research, is also assessed in this volume.

Formaldehyde is a high-volume, industrial chemical used in the production of resins. In the manufacture of particleboard or plywood, up to 10 percent of the dry weight of the finished board is resin base. The urea-formaldehyde resin in the finished product is a complex mixture of components in a state of flux. Substantial emissions into enclosed airspace, adjacent to board, may result in a characteristic formaldehyde odor.

Several techniques are available for monitoring formaldehyde concentrations in mobile homes. Reagent-filled impingers have seen the most extensive field application in monitoring the mobile-home environment. The reagent systems are most commonly analyzed by spectrophotometric procedures in the laboratory. The chromotropic acid method has been recommended by NIOSH. The pararosaniline method has been recommended by the Lawrence Berkeley Laboratory. The chromotropic acid and the pararosaniline methods are highly sensitive and specific for measuring concentrations of airborne formaldehyde. The MBTH and purpald methods have been widely used, but are not specific for formaldehyde alone.

The major deficiency of a large number of monitoring studies is the time alloted for sample collection. The sample secured must characterize the formaldehyde environment of the mobile home rather than a short-time fluctuation. A sampling period of several hours is required when a fully continuous record over a long time period is not available. The current state-of-the-art for continuous monitoring is operationally deficient in that it requires cumbersome and expensive quality assurance attention. GEOMET recommends a minimum 4-hour sampling period for chromotropic acid or 2 hours of sampling by pararosaniline.

Although there may be many potential sources, the scientific evidence indicates that particleboard and plywood constitute the major long-term sources of formaldehyde emissions in mobile homes. Factors affecting the emission strengths of these two sources include quality and age of the product, indoor temperature and indoor relative humidity. Quality of the final wood product is improving and is under continuous scientific attention by Government

and industry. The emission rate as a function of age decreases, although functional relationships have not been established. High indoor temperature and high indoor relative humidity increase particleboard and plywood emission rates of formaldehyde. Adequate functional relationships also have not been established because of the variable quality of the sources, the lack of established testing techniques, and the anecdotal nature of the few existing studies addressing this subject.

The data base for formaldehyde concentrations in mobile homes falls into two categories: (1) information available from the literature or from private sources, or (2) unavailable data that is company proprietary and is kept confidential by the industry, partially because of pending litigation. The data base that is available for assessment is incomplete, nonuniform and based on scientific reaction rather than action. Specifically, a rather large portion of the available data base does not always document all necessary input parameters, such as technique used for testing, time of sampling, indoor temperature and relative humidity. The testing techniques themselves are not uniform; many sampling approaches have been used for varying time periods that range from less than 30 minutes to more than 2 hours under a variety of monitoring conditions. Finally and most importantly, the largest portion of the available data base may be biased because almost all testing follows an explicit complaint from a resident or is suggested by a physician because of suspected formaldehyde-induced symptoms. Lacking is a standardized measurement in a statistically representative sample of mobile homes (in one state or nationwide) that will provide a uniform data base for characterizing indoor formaldehyde concentrations. Those limitations not withstanding, the available

data base shows peak values of formaldehyde concentrations that are indeed high, greater than 4.0 ppm.

Much of the available research on the human effects of exposure to formaldehyde vapor must be applied with caution to the mobile-home environment, particularly since many studies have been based on occupational exposures. Nevertheless, the preponderance of evidence is judged to be adequate to support a series of conclusions about the potential health risks associated with airborne formaldehyde concentrations in the range observed in mobile homes. Environmental health specialists have estimated that 0.5 to 1.0 percent or more of the general population in the United States have become sensitized to formaldehyde. Levels as low as 0.1 ppm and persisting over a period of months may not only be annoying to these persons but physiologically significant in terms of mucous membrane irritation, skin reactions, and chronic generalized symptoms such as rhinitis, headache and gastric irritability. It has been shown that at concentrations around 0.5 ppm both overt and latent sensitization of skin, respiratory system and digestive system can occur, so that resultant health problems could persist from subsequent low exposures even after leaving the mobile home. Data from occupational exposures suggest that fairly continuous exposure to levels below 1.0 ppm over a period of time might induce chronic respiratory inflammation and aggravate existing asthmatic and bronchitic conditions. It is likely that levels on the order of 0.3 ppm or more affect not only a small group of hypersensitive individuals, but can also produce acute symptomology in a much more substantial proportion of the general population than has been recognized previously.

The risk of more serious pathology at concentrations ranging up to several ppm can only be speculated upon with the available information. However, there are a number of points of concern. Fairly rapid accommodation to odor and minor irritant effects has been demonstrated, suggesting that concentrations that may be harmful over time may be tolerated and unrecognized. Recent reports of respiratory cancer produced in rats by formaldehyde exposure do not substantiate the chemical as a human carcinogen but do indicate residential exposures may not be without risk. Finally, two infant deaths have been associated with mobile home formaldehyde concentrations of less than 3.0 ppm. The association is clearly conjecture and has not been scientifically documented. A cause-and-effect relationship between elevated formaldehyde concentrations and Sudden Infant Death Syndrome (SIDS) has not been established. The small number of SIDS that have been registered in mobile homes is well within the random chance of occurrence. Concern has been expressed that the very young may be particularly vulnerable. The established evidence for acute effects, and the concerns raised over potentially more serious consequences, clearly indicate that exposures even on the order of a few tenths of a ppm may constitute a health hazard to more than a negligible proportion of mobile-home residents.

There are a number of standards governing allowable air concentration of formaldehyde levels. Ambient, occupational and indoor standards have been either proposed or promulgated in Europe, Japan and the United States. Most European standards are based on Danish studies. The literature does not indicate explicit means of enforcement; however, Denmark is in the process of establishing regulations regarding the formaldehyde content in particleboard.

The State of Wisconsin is currently considering standards for maximum formaldehyde concentrations inside mobile homes. This proposed standard would require the manufacturer to take action to reduce the indoor formaldehyde concentrations below the proposed standard of 0.4 ppm (0.2 ppm after May 1, 1981). The corrective action to be implemented has not been specified.

Mitigation techniques may be implemented at two different stages: (1) in the production stage, and (2) in the mobile home. Abatement techniques in the production stage have been carefully investigated. It is GEOMET's assessment that, while explicit results are difficult to find, the recent and growing consumer concern has affected the industry, and that considerable scientific effort has been focused towards reducing emissions. A cost-effective technique is the ultimate goal. Today the required additional financial burden for implementing abatement techniques ranges from 10 up to 65 percent above the present costs. The efficiency of mitigation techniques in the mobile home is unknown; claims of success vary considerably; but few, if any, have been thoroughly documented. Industrial claims for widely used filter devices must be confirmed by properly designed studies.

In order to obtain some measure of the magnitude of the formaldehyde problem in mobile homes, various state and Federal departments and agencies, as well as private organizations, were contacted. With the exception of four state agencies, in Oregon, Washington, Wisconsin, and Minnesota, the reported cases of formaldehyde problems were few in number. For example, the State Administrative Agencies, which were established to receive and respond to consumer complaints, averaged less than five formaldehyde-related complaints per state per year. However, the information provided by these contacts did

indicate that the formaldehyde problem is nationwide. Unfortunately, the nature of the information collected is such that a national estimate of the magnitude of the problem is not possible. Therefore, it was necessary to estimate the magnitude of the problem based on empirical data obtained from a few states.

The analysis of the data received from Washington, Wisconsin, and Minnesota yielded similar results. For instance, the number of reported formaldehyde problems in all three states is strongly (negatively) correlated with mobile-home age (approximately 60 percent of the affected mobile homes are less than 2 years old). Furthermore, at least 80 percent of the mobile homes monitored had formaldehyde levels less than 1.0 ppm and approximately 50 percent of the sampled mobile homes had formaldehyde concentrations below 0.4 ppm.

Using the Minnesota data as the basis for estimating the national magnitude of the formaldehyde problem, it was found that the probability of a mobile home having formaldehyde concentrations sufficient to cause irritation to its occupants was 0.21 percent per year, and that this probability was 1.87 percent during the first year of occupancy. The major limitations of the empirical data used in this analysis are as follows:

- The sampled mobile homes were not tested for the presence of other chemicals that might have caused the symptoms reported by the occupant.
- It is probable that some portion, and perhaps a significant percentage, of physicians were not informed of the formaldehyde program, and therefore failed to report, leading to underestimation of the magnitude of the problem.

- The sample may not be representative of the problem since all mobile-home occupants may not correlate their symptoms with formaldehyde, and even if they recognize the problem, they may not be aware of whom to report it to.
- The measured formaldehyde levels represent a worst-case concentration due to the measurement procedure employed.

Even with these limitations the analysis presented in this report represents the necessary first step in assessing the magnitude of the formaldehyde problem in mobile homes.

The problem that must be addressed is the growing number of complaints by occupants of mobile homes. The survey of the literature and of current relevant scientific activities illustrates that the present state-of-the-art poses as many questions as it answers. The background material summarized in this volume amply illustrates the need for a well-designed, statistically representative series of studies that will characterize the formaldehyde environment in mobile homes, and conclusively determine the effectiveness of the various abatement techniques.

Section 1.0

INTRODUCTION

Section 1.0

INTRODUCTION

The increasing interest expressed by regulatory, scientific, industrial and consumer groups about elevated formaldehyde levels in the mobile-home environment is motivated by mobile-home occupant complaints. The requirement to assess the frequency of occurrence of the complaints, the severity of the effects, the state-of-the-art on abatement or control processes and the regulatory alternatives has led to this literature search. Owing to the time constraints of the task, this document is not an exhaustive review of the literature; rather it is a comprehensive examination of the formaldehyde question.

This review examines available publications and reports on current research relevant to the indoor mobile-home environment. Approximately 90 percent of the listed papers were obtained and reviewed; the remaining portion was identified from referenced information. Because of their current involvement on projects associated with formaldehyde, several experts from the scientific, regulatory, and industrial communities were contacted. Their findings and opinions are referenced, with their expressed permission, as private communications.

The contaminant (formaldehyde) is introduced by briefly describing its physical and chemical properties in Section 2.0. The monitoring technique used to identify and quantify sources and later to measure the formaldehyde concentrations in the mobile-home environment are discussed in Sections 3.0, 4.0 and 5.0, respectively. A discussion of the health effects that may be

associated with various levels of formaldehyde are presented in Section 6.0. As a consequence of these potential health effects, several formaldehyde standards have been recommended or promulgated (see Section 7.0). In order to realize these standards, abatement techniques will be applied; the state-of-the-art of these techniques is described in Section 8.0. Section 9.0 concludes this document with a preliminary evaluation of the magnitude of the problem.

This report also includes three appendixes. The first appendix, entitled "The European Experience," discusses the results of formaldehyde-related research in Europe. Approximately 100 formaldehyde measurements were obtained from 23 Danish homes. The formaldehyde levels averaged 0.62 mg/m^3 with a range from 0.08 to 2.24 mg/m^3. The next appendix is a bibliography of the papers reviewed in the preparation of this report. The final appendix is an author listing by subject category. Thus, Appendixes B and C can be used to identify individual papers pertinent to specific subject areas.

Section 2.0

RELEVANT PHYSICAL AND CHEMICAL PROPERTIES

Section 2.0

RELEVANT PHYSICAL AND CHEMICAL PROPERTIES

Formaldehyde is a high-volume, industrial chemical used in the production of resins, chemical synthesis, fumigation, disinfection and tissue preservation. Its physical and chemical properties are described in a comprehensive monograph by Walker (1975). The following summary is limited to those aspects of formaldehyde chemistry that are relevant to evaporation of the compound from materials used in mobile homes. The section begins with general information on formaldehydes and later it focuses on aspects relevant to the mobile-home environment.

2.1 FORMALDEHYDE SOLUTIONS

Pure, dry formaldehyde is a colorless gas having a boiling point of -19°C and a freezing point of -92°C. Both the liquid and gas polymerize readily at ordinary temperatures and the monomeric form can only be maintained under special conditions. As a result, formaldehyde is sold commercially as either a solution or solid polymer. Monomeric formaldehyde can be readily prepared from both solutions and polymers and is usually generated as required at the time of use.

Formaldehyde is mainly stored and transported in the form of aqueous solutions containing 37 to 50 percent by weight dissolved formaldehyde. The 37 percent solution is most common. These solutions usually contain 1 to 15 percent methanol to prevent precipitation of solid polymers under ordinary conditions of handling and storage. Solutions of formaldehyde in the lower

aliphatic alcohols and unstabilized aqueous solutions, containing little or no methanol, are used for special purposes.

In aqueous solutions, formaldehyde exists mainly as the monohydrate, methylene glycol, $CH_2(OH)_2$, and a series of lower-molecular-weight polymeric hydrates, termed polyoxymethylene glycols, $HO(CH_2)_nH$. Methylene glycol predominates at low formaldehyde concentrations, with higher concentrations promoting formation of polyoxymethylene glycols. The concentration of the polymers and their degree of polymerization increases with increasing concentration of dissolved formaldehyde. Solubility of the polymers decreases with increasing size, and they eventually precipitate. Polymer formation is inhibited in aqueous solutions containing methanol, which condenses with formaldehyde to form hemiacetals and acetals. These do not readily polymerize and polymer formation is inhibited in proportion to the ratio of methanol to formaldehyde. Typically, 1 to 15 percent methanol is added to commercial formaldehyde solutions, the quantity added being determined by storage and use requirements.

Formaldehyde, in aqueous solution, behaves like a nonvolatile glycol, rather than a volatile gas. The stability of formaldehyde in solution is illustrated by the vapor pressure data in Table 2-1 (Walker 1975). When a formaldehyde solution is allowed to evaporate at ordinary temperatures, H_2O is lost, and the solution concentration of formaldehyde increases until it reaches 30 to 40 percent. This causes a small increase in the partial pressure of formaldehyde, as indicated in Table 2-1. Further evaporation merely results in precipitation of polyoxymethylene glycols, whose molecular weight increases as H_2O is removed. Complete evaporation of H_2O leaves

Table 2-1. Partial Pressure and Air Saturation Data for Aqueous Formaldehyde (Walker 1975)

Formaldehyde Concentration (g CH_2O/100g)	(g CH_2O/100 cc)	Partial Pressure of Formaldehyde (mm)	mg Formaldehyde per Liter Saturated Air
	Temperature = 0°C		
7.97	8.09	0.056	0.095
15.0	15.68	0.102	0.166
19.4	20.63	0.118	0.201
28.6	31.25	0.157	2.265*
	Temperature = 20°C		
9.25	9.52	0.340	0.59
18.6	19.7	0.575	1.01
27.2	29.5	0.780	1.39
28.6	31.1	0.795	1.40
36.2	40.2	1.025	1.75
	Temperature = 35°C		
1.08	1.09	0.166	0.27
5.10	5.15	0.695	1.13
11.4	11.8	1.29	2.06
18.3	18.6	1.80	2.87
19.7	20.8	1.94	3.17
28.6	31.0	2.48	4.27
35.9	39.5	2.81	4.58
	Temperature = 45°C		
10.5	10.8	2.30	3.77
19.4	20.4	3.79	6.17
27.1	28.75	4.72	7.70
35.5	39.2	5.60	9.12

* Value should be 0.265 mg/l to be consistent with partial pressure of 0.157 mm.

these as a solid residue having a vapor pressure comparable to that of the 30 to 40 percent formaldehyde solution. The low volatility of formaldehyde from aqueous solutions is the major property of the compound leading to its retention in materials made with resins containing excess formaldehyde.

2.2 CHEMICAL PROPERTIES

Formaldehyde is the simplest of the homologous series of aliphatic aldehydes. Unlike higher members of the series, the -CHO group is bonded to two hydrogen atoms. This is largely responsible for its unique reactivity, which is not modified by other functional groups or hydrogen atoms. The keto-enol tautomerism that stabilizes other carbonyl compounds cannot occur in formaldehyde. The chemical versatility of formaldehyde is illustrated by the following three categories of reactions, of which the examples cited represent only a small sample of those reported in the literature:

- Autopolymerization

  Formaldehyde polymerizes readily to form linear polymers, termed polyoxymethylene glycols, $H(CH_2O)_nOH$. The degree of polymerization varies with conditions and n can range from < 10 to > 300. Compounds with n = 6-100 are white solids, which are known commercially as paraformaldehyde and serve as a solid source of formaldehyde. Compounds with n = 100-300 are termed polyoxmethylenes. These can be modified by chemical replacement of end groups and the use of other additives to produce acetal resins, such as Delrin, developed by DuPont. Under special conditions, formaldehyde can be polymerized to a cyclic trimer, trioxane, $(CH_2O)_3$. This compound does not depolymerize on heating and is used as an intermediate in the manufacture of acetal resins.

- Oxidation/reduction

  Formaldehyde is a powerful reducing agent, particularly in alkaline solution. It is used as a reductant in metallurgy, photography, analytical chemistry and in the preparation of silver mirrors. It undergoes a Cannizzaro reaction in which it dismutates to methanol and formic acid. Crossed-Cannizzaro reactions are used to reduce other aldehydes to the corresponding alcohols.

- Addition and Condensation

  Formaldehyde undergoes aldol-type condensation reactions to produce various sugars and is an intermediate in carbohydrate synthesis in plants. It adds readily to compounds having active hydrogen atoms, such as amines, amides, alcohols and phenols to produce methylol-addition compounds. These compounds can react further with active hydrogens to produce stable methylene bridges. This property is the basis for its application in producing resins with urea and phenol, as well as for its utility in tanning leather, preserving tissues and preparing vaccines.

2.3 UREA-FORMALDEHYDE RESINS

Urea-formaldehyde resin used in the manufacture of plywood and particleboard is considered the major source of formaldehyde in mobile homes (Seymour 1979). The resins used are typically intermediate condensation products, which are not as highly polymerized as the thermosetting powders used for molding.

In the most general terms, preparation of the resins involves reaction of urea with formaldehyde to reversibly form N-(hydroxymethly) urea, known as methylourea:

$$H_2NCONH_2 + HCHO \rightleftharpoons H_2NCONHCH_2OH$$

The hydroxymethly group bonded to the nitrogen atom reacts readily with other NH groups, eliminating H_2O:

$$H_2NCONHCH_2OH + H_2NCONH_2 \longrightarrow H_2NCONHCH_2NHCONH_2 + H_2O$$

The amide groups can react with more formaldehyde to eventually produce high molecular weight chains with the general formula:

$$(\text{-NHCONHCH}_2\text{-})_n$$

These chains still contain NH groups which can react with more formaldehyde to produce methylol adducts:

$$(\text{-NHCON}\underset{\displaystyle \text{CH}_2\text{OH}}{\underset{|}{\text{CH}_2}}\text{-})$$

These adducts can react with NH groups on adjacent chains and link them through methylene bridges:

$$(\text{-NHCON}\underset{\displaystyle \text{CH}_2}{\underset{|}{\text{CH}_2}}\text{-}\quad)$$
$$(\quad\text{-NCONHCH}_2\text{-})$$

Continuation of the process produces three-dimensional macromolecules, resulting in a nonfusible resin. Some of the methylourea molecules produce cyclic polymers, which are still polyamides capable of undergoing further condensation and contribution to the structure of the macromolecules to increase their complexity.

All of the reactions indicated are more or less reversible. The methylol adducts are more labile than the methylene bridges, which are quite

stable. In general, highly polymerized resins are more stable than those with lesser polymerization. The pH, reaction medium, temperature, and ratio of formaldehyde to urea are important factors in determining the final properties of the resin. Usually, methylol derivatives, with a selected degree of polymerization, are prepared at a neutral or alkaline pH, mixed with a filler, then cross-linked (hardened) at an acid pH and elevated temperature.

2.4 PARTICLEBOARD AND PLYWOOD

In the manufacture of particleboard, enough resin base to constitute 6 to 10 percent dry weight of the finished board is mixed with wood particles, the quantity of resin being determined by the type and size of the particles. The resin is neutral when applied and the wood, with a pH of 3.5 to 5.5, provides the acidity necessary to catalyze final polymerization. The resin/particle mixture is pressed at temperatures of the order of 150°C. Press temperature and time are determined by resin formulation and the moisture content of the materials used.

Wood is not a homogeneous material, and localized areas can have significant variations in pH and moisture content. As a result, the degree of polymerization achieved in the press cycle is not totally uniform throughout the board, and microscopic zones may contain a high percentage of unreacted methylol derivatives, hydrolyzed starting material and free formaldehyde. In both particleboard and plywood, a uniform, high degree of polymerization is synonymous with good bond strength, durability and low formaldehyde residues.

The urea-formaldehyde resin in the finished product, whether particleboard or plywood, is a complex mixture whose components can be envisioned as

being in a state of flux. A schematic diagram of an idealized mixture, developed by Couch (1979), is shown in Figure 2-1. In a fresh board, the main reservoir of readily evaporable formaldehyde is water-HCHO, which can be considered analogous to the formaldehyde solutions described earlier. The vapor pressure/concentration relationships listed in Table 2-1 influence formaldehyde gradients within the board, migration to the surface and subsequent evaporation from the surface. Permeation to the surface and subsequent evaporation are complex phenomena governed by board moisture, formaldehyde content, porosity, temperature and surface properties, as well as by the temperature, humidity and formaldehyde content of the surrounding air space. Evaporation from the surface to the air space is a concentration-dependent equilibrium process. The board absorbs formaldehyde from the air space whenever the air concentration exceeds the retention capacity of the surface.

The major permanent reservoir of formaldehyde is the resin, which contains methylene bridges and end group methylol derivatives. The end groups are relatively labile and release formaldehyde, which combines with moisture in the board to replenish methylene glycol pools and form adducts with cellulose and lignin. Slow hydrolysis of the methylene bridges to release new methylol end groups also occurs.

2.5 REFERENCES

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Seymour, J.W. July 3-13, 1979. Formaldehyde Problems in Manufactured Housing. Presented at 33rd Annual Meeting, Forest Products Research Society. San Francisco, California.

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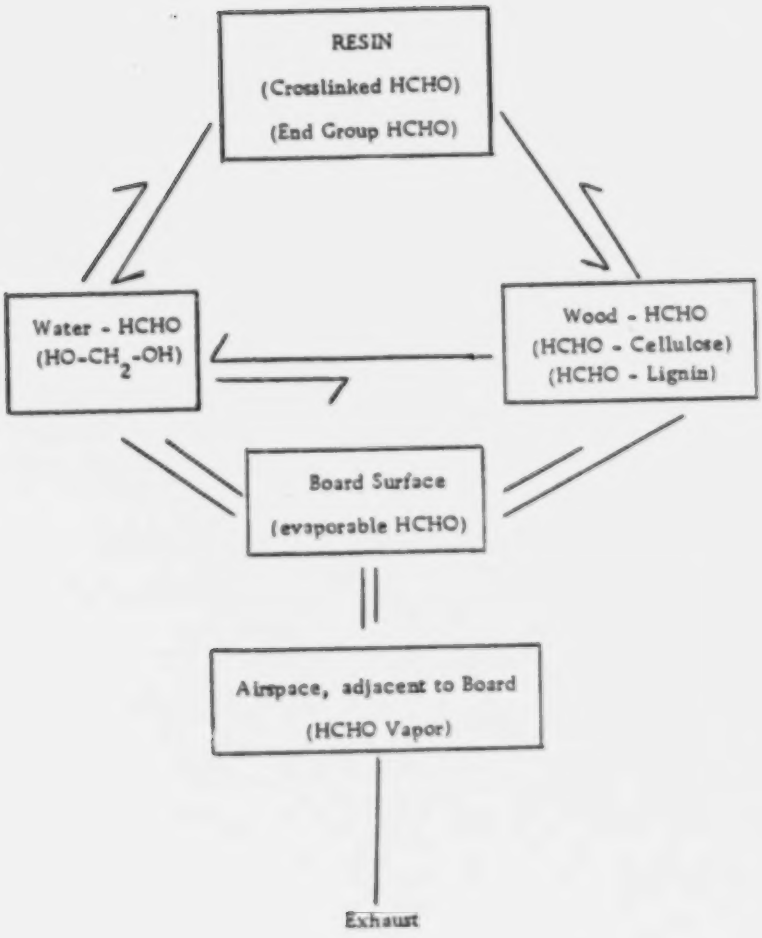

Figure 2-1. Mobility of Formaldehyde in UF Particleboard or Plywood (Couch 1979)

Section 3.0

FORMALDEHYDE MONITORING TECHNIQUES

Section 3.0

FORMALDEHYDE MONITORING TECHNIQUES

3.1 INTRODUCTION

Several techniques that are suitable for monitoring the formaldehyde content of mobile home air are available. Operational principles range from the simplicity of chemical procedures that have been in use for many decades to more advanced and emerging technologies that are still in the prototype stage. Depending upon the method employed, resulting measurements may be in the form of integrated concentrations, instantaneous concentrations, or continuous records.

Reagent filled impingers have seen the most extensive field application. The reagent systems are most commonly analyzed by spectrophotometric procedures in the laboratory. Table 3-1 enumerates the critical aspects of these methods. The chromotropic acid method has been recommended by NIOSH (1976). The Lawrence Berkeley Laboratory has refined the pararosaniline method (Hollowell 1979). The chromotropic acid and the pararosaniline methods are highly sensitive and specific for measuring concentrations of airborne formaldehyde. The 3-methyl-2 benzothiazolinone hydrazone (MBTH) and purpald methods have also seen wide use, but are not specific for formaldehyde alone. Measurements resulting from application of these methods are ordinarily integrated concentrations.

Table 3-1. Collection Efficiency and Sensitivity of Spectrophotometric Techniques

Trapping Solution, Collection Efficiency (%)	Analytical Technique	Minimum Detection (µg/ml)	Major Interferences	References
H_2O (80%) 1% aqueous HSO_3 (100%) Concentrated H_2SO_4 (99%) Chromotropic Acid (99%)	Chromotropic Acid	0.1	NO_2	NIOSH (1976)
H_2O (80%)	Pararosaniline	0.1	None	Lyles et al. (1965) Hollowell (1979)
MBTH (88%)	MBTH	0.05	Higher Aldehydes	Sawicki et al. (1961)
PURPALD (100%)	PURPALD	0.2	Higher Aldehydes	Jacobson and Dickinson (1974)

The capabilities of these and other operational and potential methods are discussed in terms of the three principles that are basic to all monitoring techniques:

1. SAMPLE COLLECTION - a controlled volume of air is collected by the formaldehyde sampling apparatus (Section 3.2)
2. SEGREGATION/ANALYSIS - formaldehyde residing in the collected sample is isolated and its magnitude assessed (Section 3.3)
3. CALIBRATION - system capabilities are referenced to acceptable standards (Section 3.4).

These three basic principles, as applied to the monitoring of gaseous pollutants in general, have been summarized by the APHA Intersociety Committee (1972), and more recently by Axelrod and Lodge (1976). The reader is referred to these two citations for more detailed information.

The assessment of monitoring systems was based upon the technical integrity of the methods and their range of application. Costs were considered in two basic classes: inexpensive (i.e., hundreds of dollars) and expensive (i.e., thousands of dollars). An overriding context applied the utility of these monitoring systems to the formaldehyde question in mobile homes. Section 3.5 summarizes these findings.

3.2 PRINCIPLES OF SAMPLE COLLECTION

All sampling methods require an accurate appraisal of the amount of air involved in the assay. Sample flow is generally induced by the vacuum action of a simple pump; placement downstream of the sensitive elements avoids problems of contamination. The mechanics of sample collection are controlled by the context of the measurement (i.e., instantaneous, continuous, integrated).

Instantaneous sampling for formaldehyde requires that a controlled volume of air be secured in a time period shorter than the constituent can be expected to fluctuate. Standard methods for "grab" sampling (i.e., pumping into bags, glass vessels, etc.) are not ordinarily employed for formaldehyde samples.

The continuous sampling mode exposes the formaldehyde-sensitive components to a steady stream of sample air, allowing short-term changes in concentration to be assessed. The integrated mode accumulates sample air over a preset time interval for analysis. Both of these modes require constancy of flow; the registry or accumulation of formaldehyde should be influenced by changing concentrations in successive but equal increments of sample air, not by changes in the size of sample increment. The simplest and most common flow regulation device is the critical orifice. This may be a simple hypodermic needle, watch jewel or glass capillary. Throughflow is linear with respect to upstream pressure as long as pump action provides a pressure drop of at least 53 percent (Urone and Ross 1979). Wartburg et al. (1973) have described a more complex system that achieves constant flow at much lower pressure drops.

3.3 PRINCIPLES OF SEGREGATION/ANALYSIS

Once volumetric integrity of the sample is assured, the formaldehyde assay may proceed. The assay is a two-step process: (1) formaldehyde is isolated from all other sample constituents; (2) the isolated fraction is quantified. The resulting concentration is a statement of the size of the isolated fraction with respect to the total sample.

In the integrated mode, the formaldehyde fraction is usually isolated by passing the air sample through sorbent media. The isolated fraction may be analyzed in situ or in the laboratory. The continuous mode generally relies upon contrast effects to isolate and quantify formaldehyde. Many of the continuous monitoring techniques employ spectroscopic measures (i.e., absorption, fluorescence, chemiluminescence).

3.3.1 Isolation Techniques for Integrated Methods

The most popular integrated methods have employed trapping solutions in bubblers or impingers. Trapping solutions range from simple distilled water to the very reagent systems used in the analysis phase. The collection efficiency of a trapping solution has obvious impact upon the utility of any scheme; if isolation of formaldehyde is poor or inconsistent, the measurement suffers. Levaggi and Feldstein (1969) have reported that a 1 percent aqueous HSO_3 trapping solution is very efficient (98 to 100 percent) for collecting various aldehydes. NIOSH (1976), among others, has reported formaldehyde collection efficiencies for water of 80 percent. Altshuller et al. (1961) have reported a formaldehyde collection efficiency of 99 percent using chromotropic acid solutions. However, collection efficiencies can approach 100 percent by placing two impingers in series. NIOSH (1976) reports that the 80 percent collection efficiency of water may be increased to a total collection efficiency of 95 percent in this manner. In field applications, the choice of trapping solution must address the stability of the isolated fraction if the material needs to be transported to a laboratory for subsequent analysis. Scientists at the Lawrence Berkeley Laboratory (LBL) have found that refrigerating

the solution during sampling and storage extends the stability far beyond the few days that ambient temperatures generally allow (Hollowell 1979). Distilled water is the most popular trapping solution due to the relative ease of handling and procurement.

Solid sorbents have seen only small use in segregating formaldehyde for analysis. Molecular sieves have been employed by Gold (1978) to trap formaldehyde; analytical techniques used water to desorb the formaldehyde for analysis. NIOSH (1977) cites a method that employs alumina as a sorbent medium; sorbed formaldehyde is eluted via a water-methanol solution for subsequent analysis by the chromotropic acid method. Sorbent capacity of the alumina is attenuated by atmospheric humidity, and the collected fraction is not stable. Semiquantitative methods have employed formaldehyde-sensitive sorbents to force a color change commensurate with the formaldehyde concentration of entrained air (Sundin 1978). These methods are most ordinarily used as an indicator. Cryogenic trapping, subambient temperature baths, were used by Bellar and Sigsby (1970) to monitor automobile exhausts; this technique is cumbersome for field operation.

3.3.2 Analysis Techniques for Integrated Methods

The analysis of trapping solutions for scavenged formaldehyde content is most often performed by spectrophotometric methods. Reagent systems force the formation of a distinctive dye chromophore that is quantified by absorption in a specific wavelength interval. A wide variety of reagent systems have been applied to this analysis; these are summarized in Table 3-1 with critical aspects of technique and usual trapping solutions. It should be

noted that the analytical reagent system may also serve as the trapping solution. The most popular technique applied to formaldehyde is the chromotropic acid method. The pararosaniline method applied by LBL is now in the testing stages and appears to be very promising.

The chromotropic acid technique has been recommended by NIOSH (1976). The method is subject to interferences from constituents that may be encountered in field applications. Most notable of these are ionized products of the oxides of nitrogen (NO_2, NO_3) that may occur in the water or acid solutions specified by the technique. Cares (1968) has investigated these interferences. Modifications to technique that combat these interferences increase the complexity. There is a lack of consensus regarding optimum preparation (West and Sen 1956, Altshuller et al. 1961), so sensitivity may not yet be fully developed.

The pararosaniline technique was found by Lyles, Dowling and Blanchard (1965) to be virtually free from interferences when used for formaldehyde analysis. SO_2 and CN^- may be interferences at very high concentrations. LBL (Hollowell 1979) has refined the technique and is introducing it into extensive field use.

Other reagent systems have been used, but have not seen as extensive use in field measurements. These have been included in Table 3-1. Many of these have been employed to measure total aldehydes, one-half to two-thirds of which is usually formaldehyde (Altshuller 1976).

3.3.3 Segregation/Analysis in the Continuous Mode

Several continuous techniques have emerged; some employ spectroscopic techniques (see Hraibesh 1973, Becker et al. 1975 for example), others have

employed chemical techniques (see Lyles et al. 1965, for instance). Application to field measurements are presently hobbled by the expense of support equipment as well as the need for sophisticated maintenance of delicate components. These techniques are not generally conducive to long-term, unattended monitoring. Specific quality assurance procedures need to be applied. The presence of a field technician is required for the duration of continuous sampling and recording because a number of automatic processes may not be performed properly unattended (Hollowell 1979 and others).

3.4 PRINCIPLES OF CALIBRATION

Calibration is a critical phase of the measurement process. Its purpose is to establish the relationship between the data produced by the monitoring technique and the reality that these data are to portray. Standard techniques require applying samples of known content to the monitoring method. The methods that have been successfully employed to calibrate formaldehyde monitoring systems fall into two general classes: static and dynamic. Static methods assemble isolated mixtures of known content; dynamic methods create a flowing test mixture of known and controllable content. The general principles of these two basic methods have been summarized by the APHA Intersociety Committee (1972) and Axelrod and Lodge (1976). Static methods have seen the most widespread use because of relative ease of employment and lower cost.

3.4.1 Static Methods

Formaldehyde calibration through static procedures has usually taken the form of standard aqueous solutions. These solutions are used to reference the accuracy of the analysis of trapping solutions. Walker (1975) has summarized

the preparation and standardization of these solutions. NIOSH (1976) has offered similar procedures for calibrating the chromotropic acid technique. Static methods are the most popular calibration techniques; this is most probably due to their low cost and ease of application as well as being mated to the most popular sampling technique.

3.4.2 Dynamic Methods

Dynamic test atmospheres may be generated by controlled release of formaldehyde into a controlled air stream. The resulting air stream of known formaldehyde content is then applied to the monitoring method as a reference.

Gilby (1979) has briefly described a system used in an inhalation study that employs saturated bubblers containing aqueous formaldehyde to generate a constant low-level formaldehyde air stream. Their technique employs continuous monitoring of the air stream to control and certify concentrations. The performance of the continuous monitors is in turn compared to the NIOSH-accepted chromotropic acid method applied to the same test atmosphere. This configuration proved to be the best of nine systems that were tested.

Formaldehyde may be injected directly into an air stream; if done properly, the injected material goes completely to the gas phase. Formaldehyde levels are controllable by metering air as well as injection. Devices using a syringe pump for injection have been described by Wilson (1958) and Levagoi and Feldstein (1969).

Controlled decomposition of formaldehyde precursors for subsequent release to dilution air has been employed by Tsang and Walker (1977) among others. Parent material decomposes to formaldehyde under thermal/catalytic control.

3.5 SUMMARY

Spectrophotometric analysis of trapping solutions dominates operational field measurements of airborne formaldehyde - particularly in those relatively few cases that have occurred in mobile homes (see Section 5.0). A commonly used system employs components that have seen service in air quality monitoring for many decades: air pump, flow regulation (usually a critical oriface or needle valve), and reagent-filled impingers. The basic functional arrangement is displayed in Figure 3-1. The unit is activated for the sampling interval, and the formaldehyde-charged trapping solution is then removed for laboratory analysis. All of the analytical techniques mentioned previously are easily performed in a well-equipped laboratory. Additionally, quality assurance is easily integrated into operational procedure by incorporation of standardized solutions (Moyer 1979). Quality assurance procedures for assessing the maintenance of constant sample flow rate are also well established (see APHA Intersociety Committee 1972 and Axelrod and Lodge 1976 for instance).

This set of methods represents an excellent mix of low cost operation and technical competence. The sampling hardware can be purchased complete for a few hundred dollars (fabricated inhouse for much less if facilities are available), and the analytical procedures can be performed at extremely low cost in a normally equipped laboratory. The NIOSH recommended chromotropic acid procedure and the emerging (LBL modified) pararosaniline method both have a high profile. Each has seen extensive field application in a wide range of sampling environments and performed well. Overly sophisticated field operators are not needed because the critical technical steps can be concentrated in the laboratory where potentially dangerous reagents may be safely and easily manipulated.

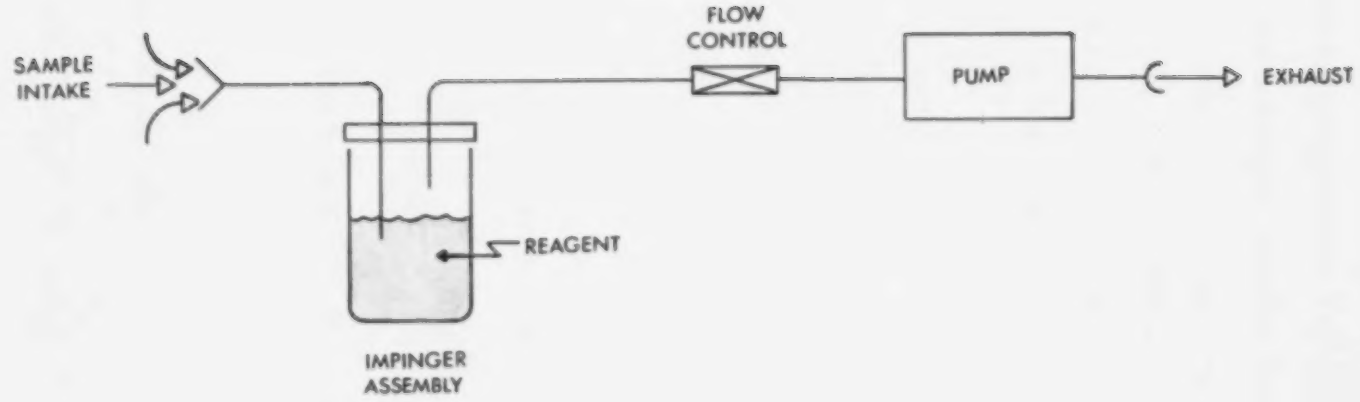

Figure 3-1. Components of Ordinary Formaldehyde Sampler

The one drawback of this class of sampling lies in the context of the resulting formaldehyde measurements; all such measurements are integrated concentrations. This makes it difficult to perceive the history of formaldehyde in the environment being assayed. A continuum could be fabricated by sequencing a suitable number of short-term integrated samples. True continuous analyzers are available, but they are expensive and require frequent calibration. This calibration is usually referenced to the chromotropic acid method by simultaneous assay of the same test atmosphere. Monitoring of airborne formaldehyde is presently at the same crossroads that monitoring of the criteria pollutants passed in the last decade - sophisticated, stable, and affordable techniques were not able to supplant bubbler/reagent systems until a large demand for such systems was apparent.

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Section 4.0

SOURCES AND EMISSIONS OF FORMALDEHYDE RELATED TO THE MOBILE-HOME ENVIRONMENT

Section 4.0

SOURCES AND EMISSIONS OF FORMALDEHYDE RELATED TO THE MOBILE-HOME ENVIRONMENT

Formaldehyde is a constituent of a wide range of materials and may be produced by some combustion processes. Textiles and fibers, paints and sealants, furnishings, and paper products are examples of formaldehyde-bearing materials that may be found in the mobile home; furthermore, tobacco smoke has been found to contain formaldehyde (Formaldehyde Institute 1979, Sundin 1978). The particleboard and plywood that are major components of the structure itself have seen the most study (Seymour 1979, Sundin 1978, Hanetho 1978, Andersen et al. 1975).

4.1 MEASUREMENT TECHNIQUES

The identity of potential sources of formaldehyde emissions in the mobile home provides only a first layer of information; the nature of the emission needs to be quantified. A systematic set of tests have been developed to address the emissions from wood products. These have been summarized by Hanetho (1978), HPMA/NPA (1979) and Nestler (1977). Four basic techniques have emerged: (1) equilibrium, (2) static, (3) dynamic, and (4) extraction. Each basic technique embraces a large number of individualized methods; the reader is referred to the citations for greater detail.

4.1.1 Equilibrium Techniques

Equilibrium techniques for measuring formaldehyde emissions place the test sample in a sealed (formaldehyde free), controlled environment. Formaldehyde diffuses from the sample until equilibrium is reached. The

air of the test vessel is assayed for formaldehyde content. This may be done by isolating the test sample from the equilibrium air and flushing the air volume through an integrated formaldehyde monitor (10 air changes will transport 99.9 percent of the original material) (HPMA/NPA 1979).

Equilibrium techniques are fairly simple, and final measures are sensitive only to the formaldehyde assay technique. If very low levels of formaldehyde result, the analytical technique may not be able to quantify them fully. Results give no indications of emission rates.

4.1.2 Static Techniques

Static techniques are similar to equilibrium techniques in that the test sample is placed in the controlled environment of a sealed vessel. The formaldehyde assay is performed in the chamber by exposing the chamber air to an aqueous collecting medium during the experiment. This technique has the disadvantage of induced high humidity, which makes it hard to compare these results with the real-world, mobile-home environment. Additionally, particles from the sample must not be allowed to contact the collecting medium because the formaldehyde assay would then reflect collection from direct solution of particles as well as that diffused from air. However, very low levels of formaldehyde may be determined by increasing the duration of the experiment.

4.1.3 Dynamic Techniques

Dynamic techniques place the test sample in a chamber that has controlled ventilation. The exhaust stream is assayed for formaldehyde content. The rate of formaldehyde emission may then be assessed as a function

of sample characteristics (porosity, density, moisture content, etc.) and environmental factors (temperature, humidity, air exchange rate). These techniques allow detailed study under conditions that may closely simulate the actual mobile-home environment. Proper deployment of this technique requires precise and complex control of the critical environmental factors.

4.1.4 Extraction Techniques

This general class of techniques requires destructive testing of the sample for formaldehyde content. The methods represent high reproducibility, but are not always diagnostic of release potential because the assay is for total free formaldehyde.

4.2 MEASURED EMISSIONS OF FORMALDEHYDE

The majority of emission testing has been aimed at particleboard and similar wood products. A pioneering study by Andersen et al. (1975) established environmental factors that control equilibrium values for particleboard. Simultaneous experiments established the importance of ventilation rate in controlling concentrations in warm air.

Sundin (1978) performed equilibrium chamber tests on a wide variety of materials and treatments. This study established a number of principles, among them:

- Products that contained urea-formaldehyde (UF) displayed equilibrium values that were clearly related to total UF content.
- The nature of the approach to equilibrium was very similar for all UF-based materials: rapid rise in the first few hours (reaching 80 percent of equilibrium in 2 hours), steady state in 24 hours.

Particleboard and several interior grade plywoods displayed the highest measured values, while several other materials used in flooring and cabinetry displayed lower values.

Seymour (1979) performed a series of equilibrium tests on various wood products, textiles, and carpets. The procedure employed two equilibrium tests on each sample with an intervening 24-hour airing outdoors. Results showed that particleboard had values a factor of two higher than that of plywood panelings, while carpeting and drapes were a full order of magnitude lower. After the airing cycle, carpeting and drapes were below detection limits, but the plywood and particleboard values had increased by a factor of three, most probably due to increased humidity. These results are displayed in Table 4-1. These results reinforce the logic of concentrating on particleboard and other UF-bonded materials found in the mobile-home environment.

The Lawrence Berkeley Laboratory (Hollowell 1979) has performed limited tests on gas ranges that indicate emission rates of formaldehyde operating in poorly ventilated rooms, which resulted in a steady state HCHO concentration of 460 $\mu g/m^3$ (368 ppb).

4.3 DYNAMICS OF FORMALDEHYDE IN THE MOBILE-HOME ENVIRONMENT

The ensemble of the above mentioned studies, though not always compatible, shed some light on the complexity of the etiology of formaldehyde in the mobile-home environment. In addition to the controls imposed by the environment, dynamic processes are occurring within the various sources, and other materials in the mobile home tend to act as transient sinks and sources.

Table 4-1. Equilibrium Levels of Formaldehyde due to Emissions from Various Materials (Seymour 1979)

Material	Prior to 24-hour airing cycle			After 24-hour airing cycle		
	Temperature, °F	Relative Humidity (%)	HCHO (ppm)	Temperature, °F	Relative Humidity (%)	HCHO (ppm)
Carpeting	85	50	0.05	85	42-60	none
Plywood Paneling	85	50	0.20	85	51-60	0.60
Particleboard	85	50	0.44	85	52-60	1.20
Drapes and Curtains	85	50	0.04	85	56-60	none
Ceiling Tile	85	50	0.06	85	52-60	none

The work of Hanetho (1978) has demonstrated the migration of formaldehyde within individual boards in response to environmentally produced gradients. The migration of formaldehyde may reverse and proceed into the board from room air if the equilibrium conditions are appropriate. The board may be viewed as a three-reservoir system composed of the resin (slow release), end groups (less slow release), and the free or evaporable formaldehyde (most rapid release) systems. The equilibrium between all phases is reversible, but less so between the resin system and its neighbors.

The situation is further complicated by the ubiquity of transient sources and sinks within the mobile-home environment. Meiners (1974) has shown that various materials, particularly fibers, can sorb (absorb, adsorb) formaldehyde when air concentrations are high. This sorbed material will be released to the air space when the (originally high) levels decline, thereby extending the residence of formaldehyde in the indoor environment. The only true sinks for formaldehyde would then involve physical removal (ventilation) or irreversible chemical transformations (scavenging). These various competing relationships are shown graphically in Figure 4-1 (Moschandreas 1979).

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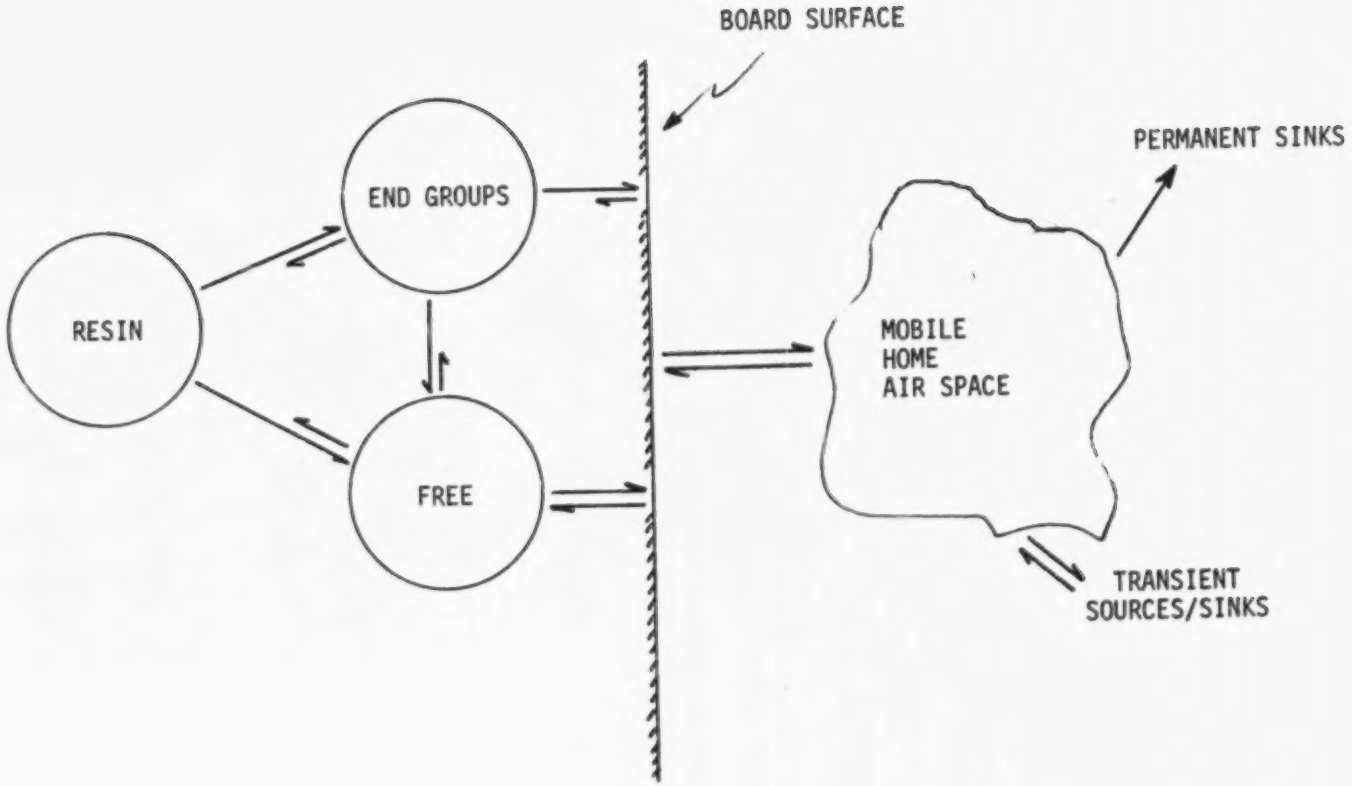

Figure 4-1. The Dynamics of Formaldehyde in the Mobile Home
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Section 5.0

OBSERVED FORMALDEHYDE LEVELS

Section 5.0

OBSERVED FORMALDEHYDE LEVELS

5.1 DISCUSSION

Few technical studies have been conducted for the determination of formaldehyde and total aldehyde concentrations in mobile homes. A summary of these studies is listed in Table 5-1.

Aldehyde concentrations averaging 1.08 ppm with maximum values of 3.8 ppm were observed in native huts in the highlands of New Guinea (Cleary and Blackburn 1968). Methods used for the determination of these values were not available. Aldehyde and formaldehyde levels have been measured for residences in Denmark, The Netherlands, the Federal Republic of Germany, and in the United States (Andersen et al. 1974, Stolwijk 1979, Moschandreas et al. 1978). Maximum formaldehyde levels observed in European dwellings had peak values of 2.78 mg/m^3, but average values were below 0.5 mg/m^3 (Andersen et al. 1974, Stolwijk 1979). Aldehyde concentrations in a sample residence in the United States did not exceed 0.6 mg/m^3 in a 4-hour sampling period. The majority of dwellings monitored registered levels below 0.2 mg/m^3 (Moschandreas et al. 1978). Sampling conducted in The Netherlands in residences built without formaldehyde-releasing materials indicated mean formaldehyde values of 0.04 mg/m^3 with peak values of 0.1 mg/m^3 (Stolwijk 1979). No sampling materials or analytical techniques were indicated for the European studies. MBTH bubblers were used to measure aldehyde concentrations in the United States.

Table 5-1. Summary of Studies on Formaldehyde and Total Aldehyde Concentrations in the Indoor, Nonoccupational Environment

Location	Total Aldehydes		Formaldehyde		Number of Samples	Sampling Technique	Source of Information**
	Range	Mean Value	Range	Mean Value			
Domestic Premises (New Guinea Huts)	3.8 ppm peak	1.08 ppm					Cleary and Blackburn (1968)
Mobile Homes in Washington State in Which the Residents had Complained of Irritation			0.03 to 1.77 ppm (0.04-2.21 mg/m^3)	0.1 to 0.49 ppm (0.125-0.6 mg/m^3) (67% of samples)	608 (334 hours)	chromotropic acid method single impinger	Breyse (1979)
Mobile Homes in Washington State in Which the Residents had Complained of Irritation			0 to 2.54 ppm* (0-3.18 mg/m^3)	0.1 to 0.39 ppm (0.13-0.49 mg/m^3) (46% of samples)	138	chromotropic acid procedure single impinger	Breyse (1979) Tabershaw and Associates (1979)
Space Capsule Simulation		1.0 ppm		0.05 ppm (0.63 mg/m^3)			Jackson (1971)
Danish Residences			2.24 mg/m^3 (1.8 ppm) peak value				Andersen et al. (1974)
Netherland Residences Built Without Formaldehyde-Releasing Materials			0.1 mg/m^3 (0.08 ppm) peak value	0.04 mg/m^3 (0.03 ppm)			Stolwijk (1979)
Indoor Concentrations from Denmark, The Netherlands, and the Federal Republic of Germany*			up to 2.8 mg/m^3 (2.24 ppm)	average values below 0.5 mg/m^3) (0.4 ppm)			Stolwijk (1979)
Mobile Homes in Pittsburgh, PA Mobile Home #1 Mobile Home #2	 0.2 to 0.94 mg/m^3 0.14 to 0.93 mg/m^3	 0.47 mg/m^3 0.39 mg/m^3				 MBTH bubblers (4-hour sample)	Moschandreas et al. (1978)
Sample Residence - Pittsburgh, PA	0.56 mg/m^3	below 0.2 mg/m^3				MBTH bubblers (4-hour sample)	
Mobile Homes in Minnesota in Which the Residents had Complained of Irritation			(< 0.1-5 ppm (< 0.1-6 mg/m^3)	0.58 ppm	109	chromotropic acid	State of Minnesota (1979)
Mobile Homes in Minnesota in Which the Residents had Complained of Irritation			~ 0.1-3.0 ppm (~ 0.12-2.8 mg/m^3)	~ 0.4 ppm (~ 0.48 mg/m^3)	~ 50	chromotropic acid	Garry et al. (1979)
Mobile Homes in Wisconsin in Which the Residents had Complained of Irritation			0.02-4.2 ppm		47	chromotropic acid	Woolbury (1979)

* Maximum value from a new mobile home sampled on sales lot.
** Additional state, local and industry sources have been contacted, but no responses were forwarded.

Aldehyde and formaldehyde levels of 1.0 ppm and 0.05 ppm respectively were determined for atmospheres in space capsule simulations (Jackson 1971). No information on analytical and sampling techniques was available.

Formaldehyde sampling conducted by Breysse (1979) in 608 mobile homes in which the residents had complained of irritation indicated formaldehyde concentrations averaging less than 0.5 ppm. Maximum values of 1.77 ppm were observed in occupied mobile homes. A maximum value of 2.54 ppm was observed in a new mobile home on a sales lot. Breysse (1979) used the chromotropic acid method approved by NIOSH as his analytical method for formaldehyde determination. However, one impinger was used instead of two (Breysse 1979, Tabershaw and Associates 1979). Aldehyde sampling conducted in two mobile homes in Pittsburgh, Pennsylvania indicated aldehyde concentrations with maximum values of less than 0.95 mg/m^3 for a 4-hour sampling period. Mean values for aldehydes were 0.39 to 0.47 mg/m^3. Aldehydes were collected by bubbling air through MBTH solutions (Moschandreas et al. 1978). The residents of these mobile homes had not registered any eye or skin irritation.

Garry et al. (1979) assessed formaldehyde levels in Minnesota mobile homes using a 30-minute sampling period for the chromotropic acid procedure. Sampling was performed at a height of 50 cm above the floor in the living room and the bedroom of each home. The citation did not clearly specify the number of measurements performed; analytical technique focused on health responses. However, results graphically indicated the age-related response of the mobile home regarding levels of formaldehyde as evidenced by Figure 5-1.

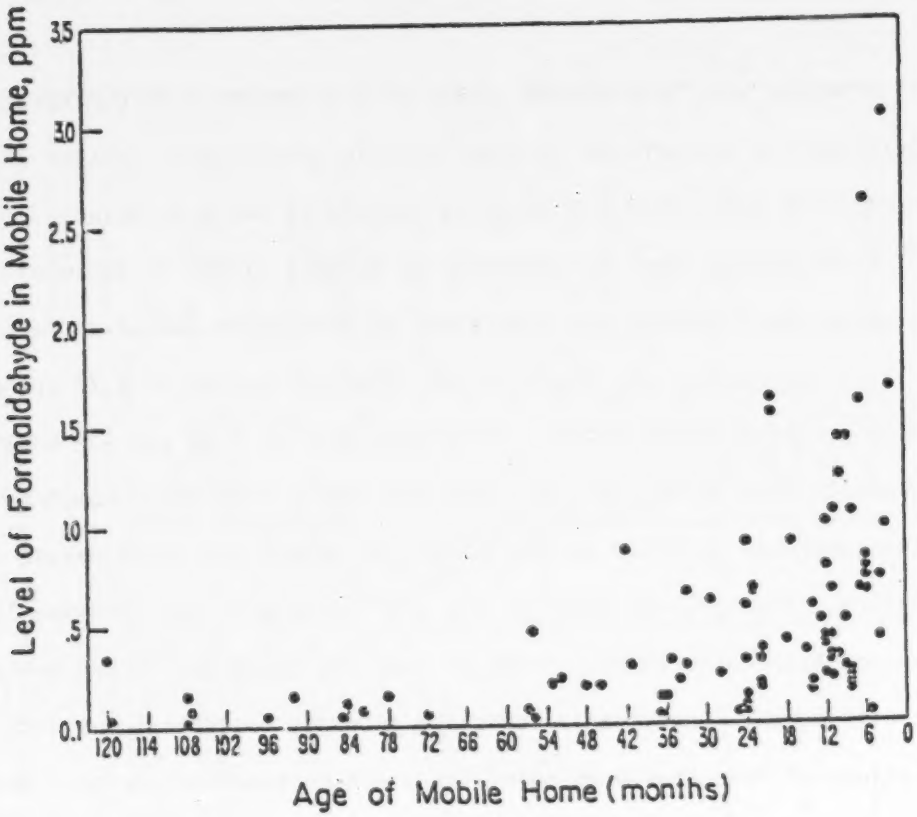

Figure 5-1. Relationship of Age of Mobile Homes to Formaldehyde Levels (after Garry et al. 1979)

Many state agencies have responded to irritation complaints in mobile homes by monitoring for formaldehyde. Data from Wisconsin (Woodbury 1979) and Minnesota (1979) have been included in Table 5-1 as examples. Measured values range from below the detection limit of 0.1 ppm to over 5 ppm (0.1 to 5.2 mg/m^3). The data obtained from Washington, Wisconsin, and Minnesota are discussed in more detail in Section 9.0 of this report.

5.2 SUMMARY AND RECOMMENDATIONS

Though a seemingly large number of individual measurements of formaldehyde levels in mobile homes has been reported, the data base available in the literature can only serve to point out the range of formaldehyde concentrations. The majority of the measurements are unified in the basic choice of sampling method (i.e., ordinarily the chromotropic acid procedure), but the comparisons among values are confounded by deficiencies in uniformity of monitoring protocol. Specifically, there is no concensus of an optimum sampling period, physical placement of instrumentation within the mobile home or the dynamic state (i.e., ventilation rate, temperature and relative humidity) of the indoor environment.

A concise statement of the range and scope of the formaldehyde question must embrace an unbiased, random sample that states the formaldehyde impact of the total population as well as the sensitive fraction. Additionally, sampling technique should recognize the dynamics of the indoor environment as well as the special nature of formaldehyde.

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Section 6.0

HUMAN EFFECTS AND DOSE-RESPONSE RELATIONSHIPS

Section 6.0

HUMAN EFFECTS AND DOSE-RESPONSE RELATIONSHIPS

In this section we have attempted to summarize current knowledge on human effects from exposure to airborne formaldehyde and to interpret these findings in light of the residential mobile-home environment. This information was drawn from three major literature reviews (NIOSH 1976, Patterson et al. 1976, Bardana 1979) and from selected published or reported research covering various facets of human response.* Also, an evaluation has been recently completed by the National Academy of Sciences (NAS 1980) that generally covers the same research material. While this brief review is not based upon an exhaustive literature search, efforts were made to include work of major importance in evaluating the formaldehyde problems in mobile homes. The reader is referred to the NAS review for more detailed coverage of pertinent studies.

6.1 CURRENT RESEARCH FINDINGS

The principal hazards for which associations with human exposure to formaldehyde have been well established are irritation of the eyes, respiratory passages, and skin. Also, the chemical has a disagreeable odor that may become intolerable at higher concentrations. A variety of acute symptoms may be produced by single or repeated short-term exposures. Respiratory symptoms include coughing and sneezing; dry and sore mouth, nose and throat; and rapid breathing or shortness of breath. The eyes may burn and

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* General findings are usually unreferenced and appear in one or more of the three major reviews. The citations from individual research reports are referenced.

tear. The skin may show evidence of contact dermatitis or allergic reactions to prior sensitization. Systemic symptoms have been reported such as gastric irritability, headache, drowsiness, restlessness, and unusual thirst upon awakening. Neurological responses have been seen in experimental exposure studies, particularly optical chronaxy and measurements of change in cortical potential.

Table 6-1 is a composite summary of acute responses to increasing dose levels. The data shown are probably best applied to adults. There is considerable variability in threshold values and tolerance levels among individuals, and a number of factors have been demonstrated to modify dose-response. Respiratory response is potentiated with simultaneous exposure to particulates or other irritative chemicals (Patterson et al. 1976, Takhiror 1974). An increased initial response was seen in mice after repeated exposures (Kane and Alarie 1977). Latent and overt sensitization of skin, lungs, stomach and intestines with single or repeated low exposures has also been reported (Kuzmenki et al. 1975).

While initial responses may increase after sensitization, there is evidence that accommodation or adaptation can occur to reduce the intensity of reactions to both odor and irritant effects. In the Kane and Alarie's animal experiments (cited above) the respiratory reaction began to fade after a few minutes, and this pattern was maintained for repeated exposures. In chamber experiments, adult males exposed to 13.8 ppm for 30 minutes tolerated the exposure, despite considerable initial nasal and eye irritation (Kulle and Cooper 1975). Both the intensity of the odor and the eye irritation were reported to decrease substantially after 10 minutes.

Some of the most widely quoted contemporary research has been conducted by Andersen and his associates in Denmark (Andersen 1979). In a chamber

Table 6-1. Acute Human Responses to Airborne Formaldehyde*

Dose (ppm)	Time	Response
0.06-0.5	Minutes	Threshold for odor and irritation of eye, nose and throat [1,2,3]; optical nerve responses in unacclimated group
0.5-1.0	Minutes to hours	Odor and irritation detectable by nearly all people; overt and latent sensitization of skin, lungs, stomach and intestines; cortical responses measurable [3,4,5,6]
1.0-3.0	Minutes to hours	Odor and irritative effects many be tolerated by normal adults; mild eye and respiratory irritation; noticeable skin irritation from direct exposure [7,8,9,10]
3.0-10.0	10-30 minutes	Approaches limits of toleration for most persons; mild to intense eye and throat irritation [11]
10.0-15.0	1-30 minutes	Profuse lachrymation and definite respiratory irritation [12]
15.0-50.0	Seconds to minutes	Burning of respiratory tract; coughing and difficulty in breathing; severe eye irritation; marked skin reactions [13]
50.0 +	Minutes	May cause serious injury to eyes and respiratory passages [13]

1 Bourne and Seferian 1959
2 Walker 1966
3 Melekhina 1964
4 Kuzmenki et al. 1975
5 Leonardos et al. 1969
6 Fel'dman and Bonashevskaya
7 Blejer and Miller 1966
8 Shipkovitz 1968
9 Pirila and Kilpio 1949
10 Kratochvil 1971
11 Patterson et al. 1976
12 Sim and Pattel 1957
13 Historical reports in NIOSH 1976

* Data is this table based on experimental exposures involving healthy adult volunteers and on observations in occupational settings. Sensitized persons, infants and young children, and persons with obstructive lung disease might have lower thresholds than those shown in the table for the various dosages. Dose ranges are only approximate and include lowest values reported in literature, without critical evaluation. This table is primarily based on dose-response data quoted in the NIOSH (1976) criteria document on formaldehyde.

exposure experiment with healthy young volunteers, subjective complaints of odor and slight discomfort were reported at concentrations ranging from about 0.2 ppm to 1.7 ppm over a 5-hour period, with the percentage of complaints increasing from 20 to 95 as the dose increased. Discomfort increased with time over the exposure period for concentrations below about 0.8 ppm, and adaptation during this period was suggested only at the highest level (1.7 ppm). There were no statistically significant differences in any of the airway resistance parameters recorded, and performance measurements on simple tasks were the same at all concentrations used. Some reduction in mucus flow was observed.

There has been little well-designed human research on the effects from long-term exposure, and most of the findings represent case reports from occupational settings. Several cases of asthma occurring after industrial exposure have been reported (Hendrick and Lane 1977). Substantially more chronic rhinitis and pharyngitis among formaldehyde-exposed workers compared to a control group has been found (NIOSH 1976). Similarly an increased frequency of acute or chronic bronchitis has been suggested for embalmers (Plunkett and Barbela 1977) and employees of kidney dialysis units (Orringer and Mattern 1976). Another occupational study found no pathological changes or decreased visual function in workers repeatedly exposed to air concentrations ranging up to about 1.5 ppm (Wayne et al. 1976).

Animal studies at concentrations below 10 ppm with exposures up to about 3 months reported continued irritative effects, reduction in body weight and chronic lung inflammation (NIOSH 1976). Workers exposed to formaldehyde vapor generated from ironing new clothes treated with urea-formaldehyde resin

have shown similar long-term irritative effects: inflammation of the eyelids, nose and throat as well as exhibiting chronic bronchitis (Kratochvil 1971).

Studies of reproductive changes in some animal species after respiratory exposure have shown evidence of affected embryonic development: increased mean duration of pregnancy, increased total body weight, decrease or increase in weight of various organs (Gofmelcler 1968, Gofmelcler and Bonashevskaya 1969). In a study of females occupationally exposed to formaldehyde, no major effects on menstrual and childbearing functions were noted (Shumilina 1975). While formaldehyde is readily mutagenic in a variety of lower organisms, no conclusive evidence for mutagenesis in animals has been identified (NIOSH 1976).

Until recently the carcinogenic properties of formaldehyde were suspected but not demonstrated. In 1963 Horton and his colleagues produced pathological changes in the trachea and bronchi of mice ranging from metaplasia to atypical squamous cell epithelium lesions with repeated exposures over 35 weeks ranging between 41 ppm and 163 ppm (Horton et al. 1963). On the other hand, Coon noted only interstitial inflammatory changes in the lungs of rats and dogs exposed to 3.8 ppm for 90 continuous days (Coon et al. 1970). In October 1979, the Chemical Industry Institute of Toxicology (CIIT) reported interim results of an animal study designed to simulate long-term occupational exposures. In rats subjected to repeated exposures (6 hours per day, 5 days per week) of 15 ppm for up to 12 months, three cases of squamous cell carcinoma were found which arose from the nasomaxillary respiratory tract epithelium. In addition, one rat exposed to the 6 ppm regimen developed cancer stemming from the skin of the nose. Further results reported in

January 1980 noted a sharp increase between the 16th and 18th month in the incidence of squamous cell carcinomas in the rats exposed at 15 ppm, resulting in a total of 37 nasal carcinomas. No further tumors have been found in the rats at lower exposures, although premalignant lesions were observed at the 6.0 ppm and 2.0 ppm levels. No neoplasms of the nasal turbinates have been identified in mice at any of the exposure levels. These data have produced a tentative conclusion of formaldehyde carcinogenesis in rats but not mice.

6.2 POTENTIAL HEALTH SIGNIFICANCE OF MOBILE HOME EXPOSURES

The research discussed above must be extrapolated with caution to exposures in the mobile-home environment. Many of the studies on formaldehyde are outdated and do not meet modern scientific standards of investigation, particularly in the measurement of formaldehyde concentrations. Occupational studies and case reports represent conditions which may not apply to residential exposure of family members: exposure only 8 hours or less per day, self-selection for tolerance, fairly high average concentrations, presence of resin dusts or other industrial irritants, experience only with adults. Experimental research utilizes healthy adults. Animal studies involve the usual questions in generalizing from the animal model to humans. With these qualifications there nevertheless is sufficient evidence to identify several aspects important in evaluating the potential health impact of the low-level exposures that may be found in mobile homes.

From case reports and limited monitoring it may be assumed for discussion purposes that average formaldehyde concentrations between 0.1 and

1.0 ppm can persist in mobile homes over periods of 12 months or more, with peak levels of several ppm. While the frequency with which these conditions occur has not been adequately substantiated, they appear to represent a situation that often has been reported.

It is clear that not only can the conditions assumed be annoying but also intolerable to many people, and might be physiological significance in terms of mucus membrane irritation. For some persons, fairly continuous exposure at these levels over a period of months could produce chronic inflammation of the respiratory tract and persistent minor symptoms such as headache, runny nose and gastric irritability. Hypersensitive persons and those more susceptible to irritant effects would experience more intense symptomology. In the latter category are infants and young children and people with asthma or chronic obstructive pulmonary conditions. Other irritants and allergens commonly present in the homes, such as components of house dust, tobacco smoke, and fumes from gas stoves and household chemicals, can produce acute symptoms similar to those from formaldehyde exposure, and combined exposures may tend to have an additive effect. It appears that contact dermatitis from airborne gaseous formaldehyde is rare; allergic skin reactions at the exposure levels frequently reported may only occur in a very small proportion of highly sensitized individuals.

The implications for longer-range or more serious health effects can only be speculated upon from the available data. There is some evidence that sensitization of skin, respiratory system and digestive system can be induced at concentrations well below 1.0 ppm, suggesting that vulnerable persons may continue to have health problems when concentrations decline in the mobile

home or when the person is exposed outside of that environment. However, there are virtually no data pinpointing minimum formaldehyde concentrations required to perpetuate or trigger recurrent disease.

A second problem area that may have long-range implications is the accommodation to odor and acute irritant effects that has been demonstrated experimentally and observed in occupational groups. After a short time, odor and irritant actions may become less noticeable to an individual through a combination of sensory fatigue and motivation, thus minimizing the tendency for those persons to remove themselves from exposure. This could make them vulnerable to persistent exposure without recognizing the cause of minor symptoms that occur. Whether, at the levels and time periods found in mobile homes, this would result in any serious illness is an open question. Data from occupational studies indicate that over time at levels of several ppm, chronic lung inflammatory changes may be observed. There is some data to suport mutagenicity. With the recent reports of carcinogenicity in rats, with some indication of a dose-response relationship, the contribution to increased cancer incidence by residential formaldehyde exposures is of concern. Thus, there is a question that a major group at risk for more serious disease might be those who became accustomed to longer-term exposure. Also, newborns may be unusually susceptible to mutagenic consequences, as well as the chronic irritation.

The extent and nature of reported formaldehyde-induced disease in mobile homes is difficult to evaluate since investigations have been uncontrolled and largely anecdotal. For these reasons this information will not be summarized here. There are though two observations on this data which seem worth including in this discussion.

First, environmental health specialists in Europe estimate that about 0.5 percent of the general population is sensitive to any concentration of formaldehyde (Foussereau and Benezra 1970, Helwig 1977). Because of our highly technological society, with the resultant increased potential for exposure to formaldehyde, there is good reason to believe that the proportion would be greater here (Bardana 1979). In the range of concentrations assumed present in mobile homes, one can speculate that perhaps 1 or 2 percent of all persons who plan to reside in mobile homes would be hypersensitive, either genetically or through induced sensitization from prior exposure. However, the hypothesis of a population subgroup hypersensitive to any concentration of formaldehyde does not appear adequate to account for symptoms in multiple family members, which has been reported in a high proportion of complaints (see Section 9.0). This suggests that a threshold for intense symptoms well below 1.0 ppm may be much more common in the general population than has been recognized previously.

The second and most dramatic aspect is the report of two infant deaths associated with formaldehyde concentrations of 2.4 ppm and 2.9 ppm, respectively (Bardana 1979). One of the infants had been born prematurely and the second was full-term, but under normal birth weight. While neither association could be specifically confirmed, there was sufficient information to suspect formaldehyde exposure as a contributing factor. The most serious concern is that, in both cases, the infants' condition became irreversible before the probable cause was recognized.

The potential link between elevated formaldehyde levels in mobile homes and Sudden Infant Death Syndrome (SIDS) has been a subject of investigation among concerned scientists. No evidence of published research could

be found. Dr. Hugh Westgate, a leading researcher on the subject, has identified five cases of SIDS in mobile homes, but a cause-and-effect relationship between formaldehyde and SIDS was established only in one case; no such relationship could be established in the remaining four (Westgate 1979). Dr. Franciosi, Chief of the Department of Pediatrics in Children's Hospital in Minneapolis, is concerned with the current lack of knowledge on the subject and stresses the need for scientifically sound and well-designed studies (Franciosi 1979). Geraldine Norris, the project director for the National SIDS program of the U.S. Department of Health, Education, and Welfare points out that while the information is available, it has not been investigated for a formaldehyde association. Ms. Norris' impression is that there is no direct association between SIDS and elevated formaldehyde levels in mobile homes (Norris 1979). The number of SIDS registered in mobile homes is not more than would be expected to occur randomly.

In summary, residents of mobile homes who are exposed to the concentrations that have been reported are subject to a problem that may likely be more than a nuisance for many persons. At the least these levels will be physiologically significant in terms of continuing minor acute symptomology. For hypersensitives, concentrations in the range of even 0.1 ppm or so may produce severe allergic reactions. While it can only be speculative at this point, there is growing concern that, because of accommodation, serious effects on vulnerable persons may not be recognized as due to formaldehyde, and that persistent, long-term exposure may increase the risk of chronic health effects.

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SECTION 7.0

FORMALDEHYDE STANDARDS

SECTION 7.0

FORMALDEHYDE STANDARDS

Standards for formaldehyde concentrations have been recommended or promulgated in many of the world's industrialized nations. The most common standards are those limiting human exposure to formaldehyde in the workplace environment. Ambient air standards for formaldehyde have been motivated by elevated formaldehyde levels where formaldehyde is produced, and in urban areas, where automobile traffic and photochemical reactions are recognized sources of formaldehyde (Cleveland et al. 1977). Standards limiting the amount of formaldehyde in nonoccupational environments have recently been considered and, in a few cases, recommended or promulgated. These nonoccupational (indoor) standards are based upon the irritating properties of formaldehyde released from particleboard, cigarette smoke, glues and bonding agents, fabrics, gas stoves, and urea-formaldehyde insulation (Hollowell et al. 1979, Andersen et al. 1975, Weber et al. 1976, Fel'dman and Bonashevskaya 1971). Recent studies indicate that formaldehyde concentrations have been most noticeable in dwellings having low indoor-outdoor air exchange rates. Ambient, occupational, and indoor formaldehyde standards (recommended and promulgated) are listed in Table 7-1.

7.1 AMBIENT STANDARDS

An ambient air quality standard of 0.1 ppm was recommended for formaldehyde in 1968 by the American Industrial Hygiene Association. No time limit is specified; however, an equilibrium value is assumed. This level was established as the lowest level of sensory irritation (American Industrial

Hygiene Association 1968). Ambient formaldehyde standards for West Germany and the USSR are 0.03 mg/m^3 and 0.01 mg/m^3 respectively (Andersen et al. 1975). Andersen et al. (1975, 1976) and Weber et al. (1976) reference the German MIK formaldehyde standard of 0.03 mg/m^3 in their studies. Melekhina determined 0.07 ppm formaldehyde to be the threshold value for eye reflex action and recommended 0.03 ppm as the maximum permissible limit for formaldehyde in ambient air (Melekhina 1958).

7.2 OCCUPATIONAL STANDARDS

The United States of America Standards Institute, sponsored by the American Industrial Hygiene Association, approved a USA standard for acceptable concentrations of formaldehyde in the workplace environment in September 1967 (United States of America Standards Institute 1967). This became the American National Standard in October 1969 when the Institute changed its name to the American National Standards Institute, Inc. (ANSI). The standard applies to all places of employment and is a recommended guide to protect the health, comfort, and well-being of workers. The standard was adopted as the U.S. Occupational Standard (EPA 1976). The level established by ANSI as the acceptable limit to avoid discomfort (3.0 ppm) is enforced by the Occupational Safety and Health Administration as a limit for 8-hour time weighted average exposure (Hollowell 1978). The American Conference of Governmental Industrial Hygienists (ACGIH) adopted a threshold limit value (TLV) of 5.0 ppm (6.0 mg/m^3) for formaldehyde at their 30th annual meeting in 1968 (ACGIH 1968). The TLV was lowered to 2.0 ppm by ACGIH in 1973 "because of complaints of irritation by exposure to formaldehyde at concentrations well below 5 ppm" (U.S. DHEW 1976).

A recommended standard for the workplace environment was developed by the National Institute for Occupational Safety and Health (U.S. DHEW 1976). A ceiling value of 1 ppm (1.2 mg/m^3) for formaldehyde was recommended for any 30-minute sampling period on the basis of "reports of irritation, objectionable odor and disturbed sleep for a few employees on exposure to formaldehyde at 0.3 ppm and of more general complaints at concentrations exceeding 2.7 ppm (U.S. DHEW 1976). In addition to these occupational standards, exposure limits for formaldehyde concentrations have been established for manned space flights by the National Academy of Sciences Space Science Board (National Academy of Sciences 1968), and for nuclear powered submarines by Naval Sea System Command (NAVSEA 1976). These exposure levels are listed in Table 7-1.

Occupational standards have been established in numerous foreign countries for limiting worker exposure to formaldehyde vapors. Some of these standards were modeled after the standards of the ACGIH. However, numerous standards have also been modeled after other standards or were originated within the countries. These occupational standards (recommended and promulgated) are listed in Table 7-1.

The National Health and Medical Research Council (NHMRC) of Australia recommends exposure limits of 2.0 ppm (2.5 mg/m^3) for formaldehyde in the working environment. These limits are listed in "Atmospheric Contaminants," written by NHMRC, and are taken from the ACGIH TLV list. These limits are recommended only and have no legal status (ILO 1977).

The TLV values (2.0 ppm or 3.0 mg/m^3) for formaldehyde, published by Belgium's Ministry of Employment and Labour, Administration of Hygiene and Occupational Medicine, are based upon the ACGIH list. These values are used as guidelines for labor protection (ILO 1977).

Exposure limits for airborne substances in the workplace are established by legislation in Bulgaria. Maximum permissible concentrations (MPC) of 1.0 mg/m^3 for formaldehydes are regulated jointly by the Ministry of Health and the Ministry of Construction and Construction Materials. A listing of MPC values is published in the Official Journal No. 88 of 1971 (ILO 1977).

Maximum Allowable Concentrations (MAC) of toxic substances in the working environment are officially established in Czechoslovakia. MAC values (5.0 mg/m^3 for formaldehyde) are not to be exceeded but time-weighted averages (TWA) of 2.0 mg/m^3 for formaldehyde are also listed as average limits for the work period. Approval of the lists is by the Ministry of Health. Values are determined based on human dose-response relationships or from MAC values established by the USSR (ILO 1977).

Finland has value limits for toxic substances issued by the Ministry of Social Affairs and Health. The values of 2.0 ppm or 2.5 mg/m^3 for formaldehyde may not be exceeded for more than 15 minutes during an 8-hour workday and are based on the ACGIH listing (ILO 1977).

Two levels of exposure to harmful substances in the working environment are established by the German Democratic Republic's Ministry of Health, through the Central Institute for Occupational Medicine. The MAK-D is the maximum average concentration permitted for a work period of 8-hours and 45 minutes. This is a time-weighted average. The MAK-K is the maximum concentration allowed for short-term exposures not exceeding 30 minutes. Both the MAK-D and MAK-K limits for formaldehyde are 2.0 mg/m^3 (ILO 1977).

Recommended standards in the Federal Republic of Germany are published by the Commission for the Examination of Hazardous Industrial Materials of the

German Research Society (a nongovernmental organization). These standards are used as a guide by labor inspectors. Initially, values were taken from the ACGIH listing, however, the MAK value for formaldehyde was reduced to 1.2 mg/m^3 (1 ppm) to avoid skin irritation (ILO 1977).

Maximum allowable concentrations (MAC) for irritants in the working environment in Hungary are listed as 8-hour, time-weighted values. The level based for sensitizers is 1.0 mg/m^3 for formaldehyde. These values may be exceeded twice during a workshift for a period of 30 minutes. The legal basis of enforcement is the "General Regulations on Accident Prevention and Health Protection," No. 6-1965-XII FSzOT (ILO 1977).

The Italian government has no exposure limits for toxic substances in the workplace. However, the Italian Association of Industrial Hygienists, jointly with the Italian Society of Industrial Medicine, has prepared a list of VLP (valori limite ponderati). The VLP or TWA guideline for formaldehyde is 1.5 mg/m^3. This list of VLPs is used as a guideline without legal obligation pending approval by the Ministry of Labour (ILO 1977).

Permissible exposure levels of toxic substances in the working environment were determined by an ad hoc Committee of the Japan Industrial Health Association. This listing of time-weighted averages has no legal status, but is used as a guide by the Ministry of Labor and by industry. The guideline ceiling value for formaldehydes is 2.0 ppm or 2.5 mg/m^3.

The Labour Inspectorate of The Netherlands publishes a list of threshold limit values (TLV) for toxic substances in the workplace. The TLV for formaldehyde is 2.0 ppm or 2.5 mg/m^3. These TLVs are based upon ACGIH

values and have no legal status, however, the values are used as an authoritative guide by the Labour Inspectorate and by industry. A National MAC Commission was set up in 1976 within the Medical Department of the Labour Inspectorate to determine exposure limits. No revised standards for formaldehyde have yet been accepted (ILO 1977).

The Ministry of Labour, Wages, and Social Affairs in Poland came into force in July 1976. A list of maximum permissible concentrations of harmful substances is enforced by health inspectors. The promulgated ceiling value for formaldehyde is 2.0 mg/m^3 (ILO 1977).

Mean concentration (TWA) and maximum concentration (MAC) values of exposure limits for toxic substances in Romania's working environments are established by the Republican Standards of Labor Protection and the Ministry of Health. The minimum level of formaldehyde is 4.0 mg/m^3. A listing of legislated standards is found in the Ordinul Ministerului Muncii (No. 34) Si Ministerului Sanatati (No. 60) of 20 February 1975 (ILO 1977).

A list of limit values for airborne pollutants is published by Sweden's National Board of Occupational Safety and Health. Ceiling values of 2.0 ppm or 3.0 mg/m^3 for formaldehyde are TWA concentrations not to be exceeded over a 15-minute period. Values are used as guidelines and are set to be below irritation levels for sensitized individuals (ILO 1977).

Maximum allowable concentration values in Switzerland's workplace environments were first established in 1945 by the Swiss Institute for Accidents Insurance. Formaldehyde limits of 1.0 ppm or 1.2 mg/m^3 for sensitizers are set to avoid any adverse effect to exposed healthy persons. These are time-weighted averages and have legal status. Enforcement is by the Labour Inspectorate and is required for all activities covered by the insurance scheme (ILO 1977).

The Ministry of Health in the USSR, with the advice of the Institute of Industrial Hygiene and Occupational Diseases of Moscow and the USSR Academy of Medical Sciences, publishes maximum allowable concentration (MAC) values. These values are declared as Soviet standards and are legally binding as absolute limits. MAC levels are set to avoid the cause of disease or any variation in the normal state of health after daily 8-hour exposure throughout the entire working life. The MAC value for formaldehyde is 0.5 mg/m^3 (ILO 1977).

Hollowell (1978) listed a promulgated occupational standard for formaldehyde in Denmark. This standard lists a threshold limit value of 1.0 ppm.

7.3 INDOOR RESIDENTIAL STANDARDS

Several countries have established formaldehyde concentration standards for dwellings. Based upon research of formaldehyde concentrations in Danish homes, Andersen recommended an interior air quality value of 0.4 ppm. Sweden accepted this recommendation and is in the process of lowering the standard from 3.0 mg/m^3 (McFadden et al. 1978, Andersen et al. 1974, Andersen 1980). Sweden also has proposed limits for formaldehyde in dwellings that include a provision to allow the Swedish Environmental Protection Board to remove the source of formaldehyde (urea-formaldehyde foam insulation and/or particleboard) from the dwelling at the owner's expense (Lindval 1979). Formaldehyde levels below 0.4 ppm are acceptable in existing buildings according to the proposed standard. Levels between 0.4 ppm and 0.7 ppm are acceptable if no irritation is experienced by the occupants. If irritation occurs at these levels, abatement action is taken. Abatement action is taken to reduce formaldehyde levels in buildings when concentrations exceed 0.7 ppm. If levels are not

reduced, action is taken by the Sweden's Environmental Protection Board at the owner's expense. These proposed standards also limit formaldehyde concentrations in new buildings (without furniture and kitchen cabinets) to levels below 0.1 ppm (Sundin 1978, Lindval 1979).

A permissible limit of 0.1 ppm for formaldehyde has been proposed by the national health authorities of West Germany (Roffael 1978). This standard, however, has not yet been promulgated.

Holland's Health Ministry has introduced a requirement limiting indoor formaldehyde concentrations to 0.12 mg/m^3. This limit is based on the German MIC standard. Final approval of this limit is pending, awaiting the determination of conditions for measurement (i.e., temperature, humidity, and ventilation) (Wulkan 1979).

The Netherlands has promulgated an indoor standard of 0.1 ppm maximum formaldehyde concentration (Hollowell 1978). Details of the development and enforcement of this standard were not obtained.

Additionally, indoor standards have been recommended for formaldehydes in Denmark dwellings. The maximum recommended value of 0.12 ppm has been proposed (Hollowell 1978). Denmark had previously controlled formaldehyde levels in dwellings with development of an emission standard (McFadden et al. 1978).

7.4 MOBILE HOME FORMALDEHYDE STANDARD

The State of Wisconsin has a proposed rule that specifies maximum formaldehyde concentrations in mobile homes. Table 7-2 shows the recommended levels. The rule states that "mobile homes shall be designed and

constructed to meet the indoor air formaldehyde concentrations established..." (State of Wisconsin 1979). The rule specifies the NIOSH analytical methods as the testing methods, and "actual living conditions" as the testing conditions. Neither the duration of the sampling period nor what constitutes "actual living conditions" are explicitly stated. Corrective actions are to be taken by the manufacturer within 30 days of departmental notification. The corrective steps to be implemented by the manufacturer are not explicitly stated. However, the possibility of using dilution air provided by mechanical means to satisfy the above levels is clearly stated. No mention is made of the costs associated with mechanically bringing in and conditioning the ambient dilution air.

Table 7-2. Wisconsin Formaldehyde Standard for Mobile Homes

Effective Date	Maximum Formaldehyde Concentration
May 1, 1980	0.4 ppm
May 1, 1981	0.2 ppm

After the manufacturer takes corrective steps, the mobile home air will be retested to certify that low levels have been reached.

If the formaldehyde levels in the mobile home are lower than the standards yet the owner has complaints, he may submit a medical report to the State, and to the manufacturer and dealer. Should this medical report associate the noted health effects with formaldehyde exposure, the manufacturer and dealer will take steps to reduce the formaldehyde concentrations to a level (undefined) that poses no health risk to the occupant. Only in the

absence of medical findings must the occupant and the dealer agree on responsible steps that will reduce the formaldehyde levels.

An important aspect of this rule is that "... prior to sale, the purchaser shall be notified in writing that the mobile home contains low concentrations of formaldehyde which can be an irritant to some people."

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Section 8.0

ABATEMENT TECHNIQUES

Section 8.0

ABATEMENT TECHNIQUES

Considerable effort has been employed to reduce the formaldehyde concentrations inside mobile homes. It is generally accepted that one of the most efficient approaches to reduce pollution is to concentrate on the source and reduce pollutant emission rates. In the case of the mobile home formaldehyde levels, three broad mitigation categories have been identified:

- Improvements in the production step of potential formaldehyde sources
- Onsite (inside the mobile home) reduction of emissions (off-gassing)
- Formaldehyde levels may be decreased by increasing the mobile home ventilation rates.

This last approach does not attempt to alter the emission strength of the source, but it does improve the indoor air quality. Recent research efforts on abatement techniques and general considerations/costs are discussed in this section.

8.1 ABATEMENT TECHNIQUES AT THE PRODUCTION STAGE

Off-gassing from building materials may result from "...freed and free formaldehyde in urea resins" (Howlett 1979). This distinction, explicitly made by many others, is of importance because it affects the time scale of emissions. Certain quantities of formaldehyde are necessary to set a resin; any excess is free formaldehyde that will be emitted as a relatively short-term effect. Efforts to reduce the excess formaldehyde content in the resin systems will be discussed in this subsection.

The parameter of importance is the molar ratio of formaldehyde to urea in UF resins. In West Germany and other countries, UF resins with a molar ratio down to 1.3:1 or below are now technically used for production of particleboard. The ratio of formaldehyde to urea in UF resins must not be decreased below a certain limit; such action would impair the strength of particleboard and increase the cured resin solubility in water (Roffael 1978).

Formaldehyde release from particleboard can also be reduced by partial substitution of UF resins by other substances that do not liberate formaldehyde. Spent Sulfite Liquor (SSL) is one such substance that is both inexpensive and abundant. Ammonium-type lignosulphonates used in a 20 percent mixture with UF resin in the outer layers of particleboard significantly reduces formaldehyde release without greatly affecting the physical-mechanical properties of particleboard. Table 8-1 shows the influence on formaldehyde release by using this type of lignosulphonates in the outer layers of particleboard. In this study, the formaldehyde emissions were measured with the Perforator test (an extraction technique) and WKI-Method (static) test (see Section 4.0).

Table 8-1. Influence of using lignosulphonates (SSL) as a partial substituent for urea-formaldehyde resins (UF) on formaldehyde release (mg/100 g) as measured by the Perforator and the WKI-Method (reaction time: 48 and 72 hours)

Resin Level in the Outer Layers in %	Unconditioned			Conditioned		
	WKI-Method (mg/100 g)		Perforator-value (mg/100 g)	WKI-Method (mg/100 g)		Perforator-value (mg/100 g)
	48 hours	72 hours		48 hours	72 hours	
10 UF	220	299	172	180	218	144
8 UF + 2 SSL	176	233	130	137	175	116

Source: Roffael, E., 1978.

A combination of lignosulphonates and an acid-tolerant phenolformaldehyde resin has been proposed for treating the outer layers of three-layer particleboard, while the cores are bonded using the conventional method with UF resins. Preliminary results, presented by Roffael (1978), are promising regarding reduction of formaldehyde emissions.

Using phenol-resorcinol resins to make particleboard can significantly reduce formaldehyde emissions; however, the high price of these resins prevents their practical use as particleboard binders (Hanetho 1978). It is also questionable whether phenol resins will be readily available for commercial use.

The difference in formaldehyde emissions from particleboard bonded with high- and low-formaldehyde resins decreases gradually by aging the particleboard. However, the leveling-off process is a long-term effect and may take more than a year to stabilize. Thus, resins with as low a formaldehyde content as is technically possible are preferred for decreasing the in-mobile-home formaldehyde levels (Roffael 1978).

In the manufacturing of plywood, both sides of the plywood were sprayed with aqueous urea solutions before and after hot pressing. This procedure results in a product with reduced free formaldehyde content and thus a lower formaldehyde emission rate (Kitakado 1973).

Various flours may be added as fillers and/or extenders to urea-formaldehyde resin. Due to the protein content of these flours, formaldehyde emissions are reduced (Nestler 1977).

Calcium lignosulphonate may also be added to urea and/or melamine resin adhesive to produce a formaldehyde-free adhesive for making plywood.

Wheat flour was also added to produce additional formaldehyde scavenging action. Test boards showed less than 0.3 ppm formaldehyde (desiccator method) with the additive while the untreated board had 20.0 to 30.0 ppm formaldehyde (Kawashima 1974).

Minemura and his collaborators (1975) report that the emission of formaldehyde from plywood was reduced by using melamine or potato protein plus urea in the adhesive formula; the veneer moisture content should also be low.

Additives to urea formaldehyde resin lead to reduction of formaldehyde odor from plywood. While a curve that relates formaldehyde levels to odor intensity is not presently available, it is clearly assumed that lack of formaldehyde odor indicates reduced levels of formaldehyde. Inui et al. (1974) report that enzymes plus wheat flour added to a urea-formaldehyde resin resulted in a low free-HCHO content. The enzyme was determined to be the cause of the reduced formaldehyde emission from the finished plywood. Inorganic peroxide (H_2O_2) may also be added to urea-formaldehyde in plywood manufacture. The resulting plywood had no formaldehyde odor (Miwa and Ochiai 1974). A varnish containing an acid amide polymer that acts as a scavenger for formaldehyde may be applied to various wood-base fiber and particle-panel materials. This varnish not only seals the panel from humidity, but also reduces formaldehyde emission by twofold (Minoji et al. 1976).

Other practices at the manufacturing stage have lowered formaldehyde emissions from particleboard used in mobile-home construction. These practices have increased this manufacturer's production costs by only 5 to 10 percent,

but because of the uniqueness of this particular plant, these procedures may not be universally applicable (Wetzel 1979):

- Use of Douglas Fir almost exclusively as the raw material for particleboard production. This results in a controlled pH level in the raw material and makes it easier to tailor a low formaldehyde resin for the particleboard.
- Use of a 6:1 molar ratio resin. Independent laboratory tests have indicated that consistent use of this resin in the manufacture of a brand of particleboard decking reduces the particleboard formaldehyde emissions by about 75 percent.
- Use of an older type Bison Blender which is larger and has a longer dwell time than many newer models that do not blend the low formaldehyde resins as well.
- Pressing the particleboard to close thickness tolerances. This allows the particleboard decking to remain unsanded. It is common knowledge in the industry that sanding increases formaldehyde emissions from particleboards. Unsanded Douglas Fir particleboard does not absorb water as readily as other particleboards. This reduces formaldehyde emissions by reducing hydrolysis (which breaks down the urea formaldehyde molecule and results in additional free formaldehyde in the board, and eventually more formaldehyde emission to the air).
- Use of a single-opening press has some advantages for lower formaldehyde levels than multiple-opening presses.

In conclusion, several methods of reducing formaldehyde emissions have been researched, and the research findings appear to be promising. One specific and preferred method has not surfaced.

8.2 ABATEMENT TECHNIQUES IN THE MOBILE HOME

The process applied in the mobile home to reduce formaldehyde concentrations after elevated formaldehyde levels have been verified is known

as retrofit. A variety of sealants and scavangers were tested by Seymour (1979) who evaluated the following materials:

- Sealants--vinyl acetate (Valspar "Zip Seal"), latex base synthetic emulsion (Valspar), clear polyurethane (Deft "Defthane"), clear polyurethane (Star Bronze "Zip Guard"), alcohol and ester base (Fuller-O'Brien "Pen Chrome")
- Scavengers (aqueous solution)--modified corn flour (Krause Milling Co. "Pro-Star"), gelatin protein (Knox gelatin), powdered egg white.

A testing of these materials led to a taxonomy according to their effectiveness to reduce formaldehyde levels. Following these tests, the decking and cabinetry of a "number of mobile homes where a complaint had been received" were sealed with polyurethane. Also, research on scavengers was performed in the same studies. This series of studies was undertaken under well-defined scientific conditions. Seymour's conclusions follow:

"1. Sealing appears to be more effective on older materials. This may indicate sealants are more effective in reducing hydrolysis than as formaldehyde barriers.

"2. The age of the UF resin may be a factor in liberation of formaldehyde. This test indicates a 'peak' period of formaldehyde liberation in the plywood under controlled given conditions of heat and humidity.

"3. The release of formaldehyde by hydrolysis in particleboard extends over a longer period of time than the plywood, and may be the primary contributor to formaldehyde gas in homes in excess of one year old."

A series of tests have been undertaken in a specially built steel test chamber with controlled environmental conditions. Figures 8-1 and 8-2, reported by Sundin (1978), show the results of various surface treatments of particleboard.

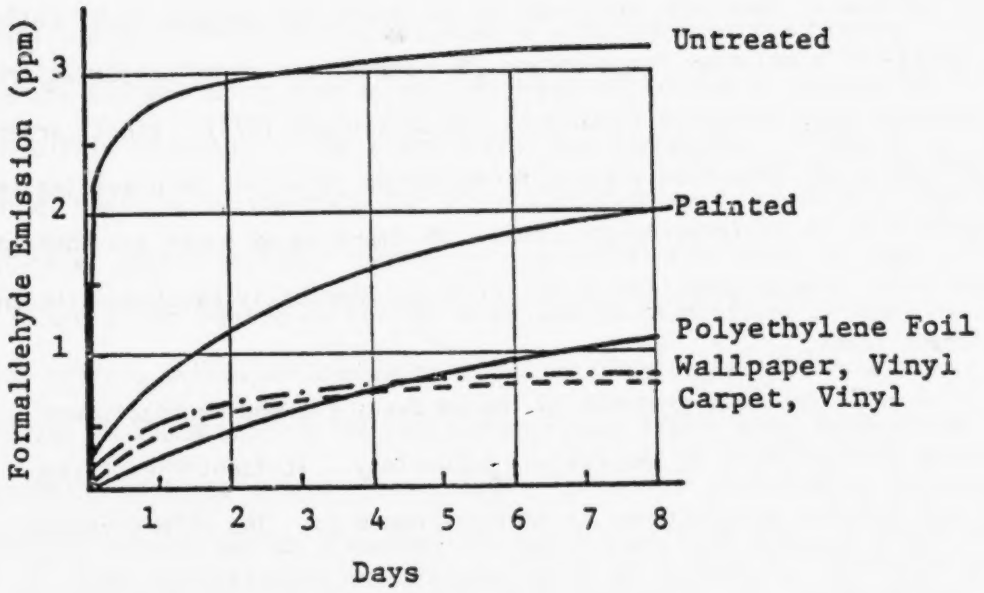
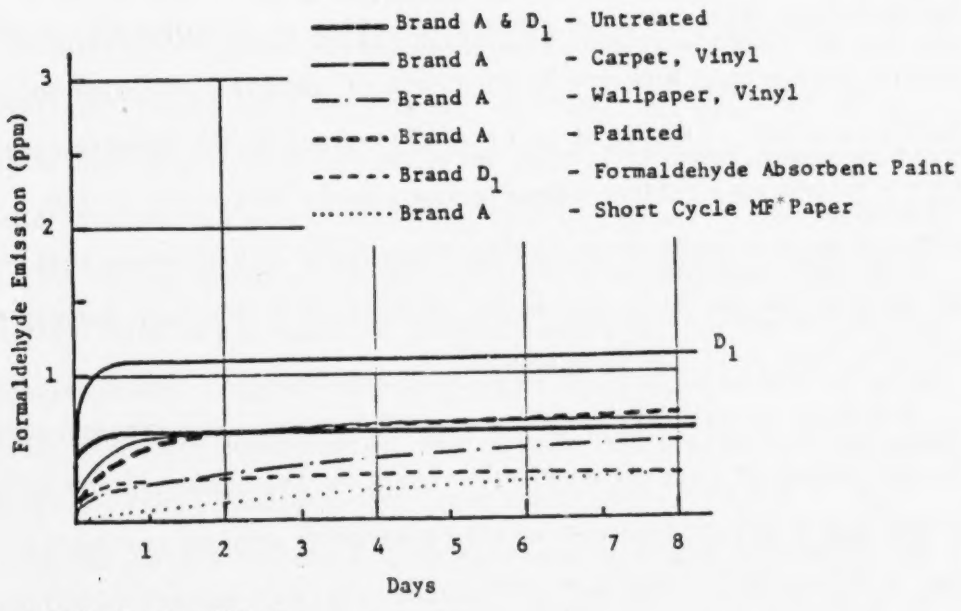


Figure 8-1. Formaldehyde emission from untreated and treated interior particleboard bonded with UF resins (Brand D board with a perforator value of 0.061%). (Sundin 1978)



* Melamine formaldehyde

Figure 8-2. Formaldehyde emission from untreated and treated interior particleboard (perforator value of 0.022% for Brand A and 0.034% for Brand D_1 board). (Sundin 1978)

It can be seen from the 8-day tests that vinyl carpet, vinyl wallpaper, short-cycle melamine formaldehyde (MF) paper, and formaldehyde absorbent paint were the most effective techniques tested (Sundin 1978). Vinyl carpet and vinyl wallpaper effectively block formaldehyde emissions by providing an impermeable surface to formaldehyde fumes. MF-impregnated paper and formaldehyde-absorbent paint reduce formaldehyde emissions by chemically reacting with the formaldehyde fumes.

A draft document prepared by the Hardwood Plywood Manufacturers Association (1979) refers to the sealant technology. It identifies five sealers and finishes manufactured by various companies. The effectiveness of these materials varied from 18 to 99 percent; the effectiveness was assessed by commercial laboratories.

Treatment with ammonia gas has been used in Austria to fumigate formaldehyde fumes (Neusser and Zentner 1968). Published reports (Sundin 1978, Roffael 1978) claim 50 to 60 percent reduction of formaldehyde levels using ammonia treatment. Repeated applications of ammonia-containing solutions may be required. Discoloration of some finishes by the ammonia require special care before application. Ammonia may also be sprayed in a room, however the Hardwood Plywood Manufacturers Association (1971) warns that spraying requires the use of a face mask. Ammonia is an irritant and may not be a desirable substitute for formaldehyde.

The most recent formaldehyde abatement technique was demonstrated. The principal author of this document was present in the demonstration of the Mortell Hyde-Away liquid introduced as a safe oxidizer with no residuals. Hyde-Away, it was claimed, substantially reduces elevated ambient formaldehyde

by contact. A test demonstration resulted in a decrease of the chamber formaldehyde concentration from an initial level of 3.8 ppm to a final of 0.75 ppm within 45 minutes. The chamber test was successful. There is no statistical basis to substantiate the success of Hyde-Away; there is a lack of application of direction under "real-life" conditions (how often do you survey?), and a requirement exists for a documented association between the Hyde-Away effects and indoor temperature and relative humidity. Most importantly, the oxidizer is known only to the manufacturer, and there is no independent substantiation that the aerosol introduced in the indoor environment does not induce health hazards by its presence. In conclusion, Hyde-Away, a potentially powerful tool for decreasing formaldehyde concentrations, must be scientifically tested regarding its effectiveness by a scientific entity not related to the manufacturer.

In 1971, the Hardwood Plywood Manufacturers Association recommended a number of methods to control formaldehyde emissions from panels in confined, poorly ventilated living areas such as mobile homes. Air purification or refreshing methods may be used to reduce the effects of formaldehyde emissions. "Sanfac Gone" concentrate (wick-bottle application) is one of the suggested products. The active ingredient in this product is an odorless, high-grade petroleum distillate and is reported to reduce physiological irritation due to formaldehyde fumes. Another similar product is called "Solidaire" which is a water-based gel, odor counteractant that reduces and replaces formaldehyde fumes (Hardwood Plywood Manufacturers Association 1971).

Another method to reduce formaldehyde emissions suggested by the Association is to heat the mobile home to at least 90°F for a few hours

followed by a complete venting of the home. Repeating this cycle six or seven times "usually corrects" the formaldehyde problem. This claim has not been documented.

A final recommendation in the Hardwood Plywood Manufacturers Association's document (1971) is to burn a sulfur candle which will cause a reduction of formaldehyde concentrations in a mobile home. This procedure, however, tends to discolor any metal that is present.

A varnish or lacquer finish applied to the exposed panels, especially the edges of the panels, will reduce formaldehyde emissions (Kitakado 1973). Chalmin (1965) suggests finishing the paneling with a colorless finish containing 1-cyanoguanidine. It is stated that the finish absorbs formaldehyde. Similarly, Nishino and Shikada (1972) indicate that building-board formaldehyde emissions may be reduced by 90 percent by spraying the boards with an aqueous solution of aminoguanidine-HCl.

Ohno and Furudera (1974) tested and found the following four aqueous ammonium solutions suitable for formaldehyde odor removal from plywood and particleboard: (1) $NH_4Cl + NaHCO_3$, (2) $NH_4OAc + NaOH$, (3) $(NH_4)_2CO_3 + Ca(OH)_2$, and (4) $NH_4Cl + Na_2SO_3$.

Ultraviolet light has been used to generate ozone that in turn oxidizes formaldehyde to carbon monoxide and water (Summer 1963). This method has been applied on an industrywide scale; however, no references are found for such application in the mobile home unit scale. In addition to the potential hazard of ozone to human health (ASHRAE 1972; U.S. Department of Labor, OSHA 1971; Diaper 1972), the effectiveness of the ozone technique

on either scale is not clearly established (Nestler 1977, Hardwood Plywood Manufacturers Association 1979).

The particleboard industry has implemented a three-step process to remedy verified complaints of elevated formaldehyde concentrations in mobile homes: (1) treat surfaces of the mobile home with one of many applicators mentioned earlier, (2) introduce a filtering device, and (3) totally remove the particleboard (Howlett 1979). The third step is used "very rarely" because the industry has been "successful" in reducing formaldehyde levels. Activated carbon filtering devices and other adsorbing sorbent media are frequently applied.

Four major classifications of formaldehyde control devices can be identified: (1) activated carbon, (2) oxidizing systems, (3) air-to-air heat exchange units, and (4) formaldehyde barriers. Activated carbon, by far the most popular, is not very effective in the removal of formaldehyde; however, when properly treated with certain chemicals, the efficiency of the activated charcoal can be increased by a factor of 10 or more (Hardwood Plywood Manufacturers Association 1979).

Purafil is probably the best known oxidizing system for purifying air. It is made by impregnating activated alumina (Al_2O_3) with potassium permanganate ($KMnO_4$) (Hardwood Plywood Manufacturers Association 1979). Sorption and oxidation are the operating mechanisms. Like carbon, the activated alumina furnishes the surface and the chemical, or the $KMnO_4$ provides the means that ties formaldehyde in the filter. Comparative tests using activated carbon and permanganated alumina filters to control formaldehyde levels have indicated that the permanganated alumina is the more effective method (Turk et al. 1973).

Earlier, Nishino and Shikata (1972) suggested that one or more of the noble metal elements Ru, Rh, Pd, and Pt may be used as oxidation catalysts at room temperature (20°C) and high humidity (e.g., 80 pct RH). A yarn, thread or fabric made from protein fiber, or a fiber impregnated with proteins may be used as a carrier for the noble metals. Like the activated carbon and the Purafil, this type of catalyst form is applicable to the design of a compact, portable recycle ventilation unit for use in removing formaldehyde odor from occupied spaces (Nestler 1977).

MnO_2-CuO catalyst in tablet form may be used at room temperature as a filter to reduce formaldehyde concentration in the indoor air. This catalyst can be regenerated (Kobayagawa and Nakajima 1974).

Clay (e.g., bentonite), starch, or carboxymethyl cellulose mixed with an aqueous solution of alkali or alkaline earth metal sulaminate, and shaped and dried, can be used as a formaldehyde adsorbent (Suzuki and Honjo 1973).

All these systems may be incorporated in the existing heating and air conditioning systems, or could be used as small individual units.

Formaldehyde barriers are simply formaldehyde-impermeable materials. Some of the better known materials, vinyl wallpaper and vinyl carpet, have been shown to be effective in reducing formaldehyde emissions (Sundin 1978).

8.3 INCREASED VENTILATION RATE

Increasing the ventilation rate provides an additional means to decrease formaldehyde concentrations in the mobile home. This effect is illustrated in Figures 8-3 and 8-4 for untreated and treated particleboard, respectively (Sundin 1978). A redesign of the ventilation system may be

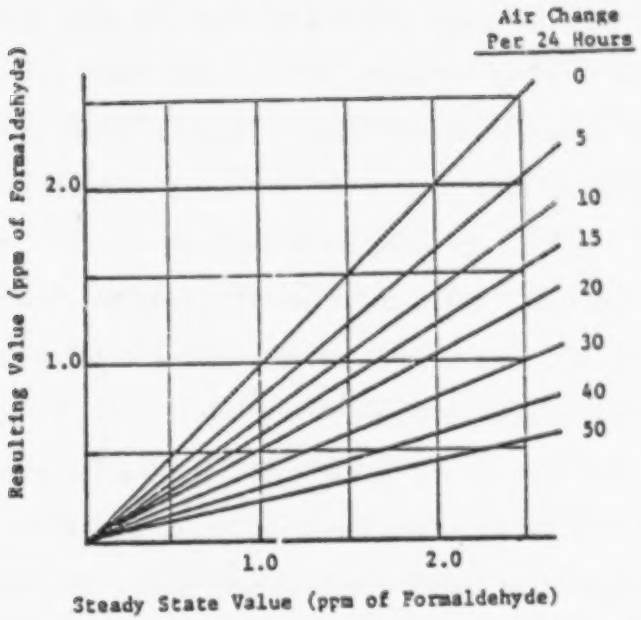


Figure 8-3. Effect of air changes on the formaldehyde content in a room containing untreated particleboard. (Sundin 1978)

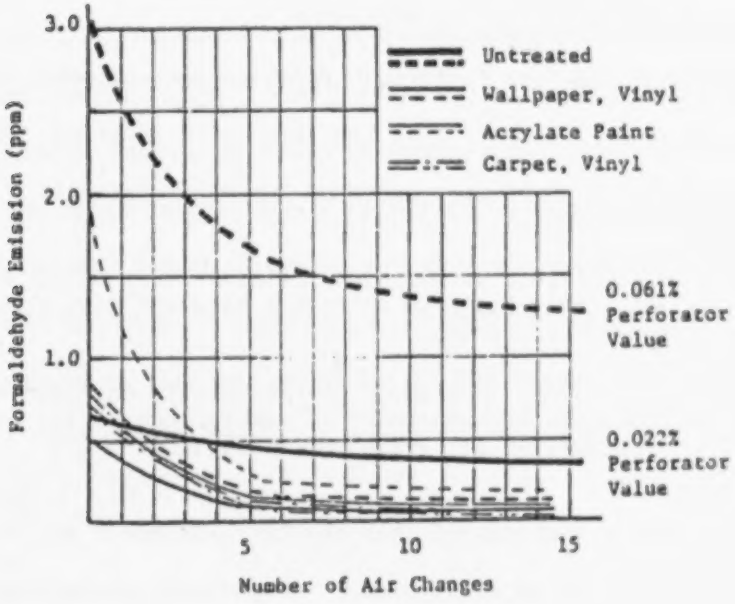


Figure 8-4. Retarding effect on formaldehyde emission by various surface treating of particleboard (load 1 m^2/m^3 air). (Sundin 1978)

necessary in order to increase the makeup (outside) air that is brought into the system. The required volume of dilution air could be calculated if the emission rate of formaldehyde was known. The main disadvantage of this technique is the increased cost of heating or cooling the outside air (Tabershaw and Associates 1979). Air-to-air heat exchangers are now being tested as energy conservation devices. While their use as formaldehyde reduction control systems is not yet known, it is currently being studied by Lawrence Berkeley Laboratory (Hollowell 1979) and its subcontractors (Moschandreas and Talbott 1979). The studies are in early stages, and therefore no conclusions have been reached. Ventilation without recirculation appears to be the only effective means of minimizing indoor formaldehyde levels (Breysse 1979). Ventilation is most effective with high temperatures and low atmospheric relative humidity since the formaldehyde fumes are less likely to be adsorbed on room surfaces (Braswell et al. 1970).

8.4 COST FACTORS IN FORMALDEHYDE ABATEMENT

Assessment of cost factors in formaldehyde abatement can only be performed in general terms within the scope of this study. Meaningful, quantified generalization is confounded by two major factors:

1. A regulatory vacuum--cost effectiveness cannot be adequately explored without a hard and fast standard that is to be met
2. Variability in production--materials, engineering processes and economics if manufacture varies considerably at all scales of analysis.

As stated in previous sections of this chapter, abatement application may be sorted into two basic sectors, production and post-production.

8.4.1 Cost Factors in Formaldehyde Abatement: Production Measures

Two major engineering points of attack have been identified in this sector, materials that make up the product and engineering processes that convert raw materials into the product. In concept, focusing abatement in this sector would represent the most elegant solution to the problem of elevated formaldehyde levels in the long run. This would concentrate the technical aspects of recognition, control and policing spatially and financially.

Bruce (1970) has simulated production costs for a generalized particleboard plant. The two dominating elements of his analysis proved to be press cycle time and resin; their joint impact represented 35 percent of the total cost. Modifications to the resin system are usually reflected in the press cycle. Stockmann (1979) has estimated that conversion to a 95:5 urea:phenolic resin system represents up to a 60 percent increase in costs because press cycle time must be doubled (thereby halving throughput) and because the phenolic component is three times as expensive as the urea. Similar problems would be encountered with other modifications to the resin system. Urea-formaldehyde enjoys a comfortable position in the raw materials market--its raw sources are not as severely impacted by increased demands from the remainder of the petrochemical arena as are other resin components; additionally, the per-pound cost of urea-formaldehyde resins is ordinarily one-third to one-quarter that of other resin systems (White 1979).

The situation is further confounded by the use of imported wood products; domestic fabricators have no a priori control over the formaldehyde-releasing potential of such products.

More recently, another industrial source provided the following estimates for various products used in mobile home construction. The cost of improved decking or flooring materials is increased between 5 to 20 percent over commonly used boards. Introduction of scavengers causes additional costs. The expense involves a production cycle slowdown. In addition, a production problem because of "gum up" does not allow recycling of the trimmings which would normally end up as hog fuel. Phenolic resins require twice the production time of conventionally used resins. In addition, the same industrial source estimates that production time is doubled, chemical costs are doubled and the per board price is nearly doubled. Softwood plywood, an alternate to particleboard, will cause an increase of between 20 to 30 percent. Practical problems associated with softwood plywood include its size, which is not amenable to mobile home needs. Finally, formaldehyde emissions from the cabinets can be controlled easily with minimal additional costs.

Whenever possible, GEOMET checked these industrial estimates against available information from Wall Street publications. The estimates are within the published range; one must consider the lower end of the indicated range when large volumes of materials are involved.

8.4.2 Cost Factors in Formaldehyde Abatement: Post-Production Measures

Material costs for the various sealants and coatings discussed in Section 8.2 range from less than $20 dollars to over $100 per hundred square feet of application. These measures could be readily incorporated into the final steps of mobile home fabrication. Fumigations with ammonia are extremely inexpensive if the trial avoids marring sensitive finishes. Catalytic scavenging via purifying recirculation costs are on the order of a few

hundred dollars; there is an added burden of changing the active elements. This represents not only a recurring cost element, but a possibility for repeated exposure to elevated levels if protocol is not closely followed. Increased ventilation has demonstrated capabilities in suppressing formaldehyde levels but may carry untenable penalties in energy consumption (even when teamed with heat pumps) except in very favorable climates (Moschandreas and Talbott 1979).

The industry is using a filter device that can operate in the middle of a mobile home. Should the industry claims be substantiated, this device may provide the most cost-effective abatement technique. It is inexpensive, in the neighborhood of $200, and it reduces formaldehyde concentrations to very low levels. An independent assessment of the effectiveness of the filtering device is required.

8.5 CONCLUSIONS

Several methods and devices have been studied to reduce the formaldehyde concentrations inside the mobile home. While a number of the studies are sound scientific works, they provide no means for generalization. Unfortunately, the industrial studies that constitute the larger portion of the effort either do not quantify or do not document the claims of rather high efficiency in reducing formaldehyde concentrations. In addition, the vast majority of the studies undertaken did not perform experiments under the same or similar conditions (or they do not report the environmental conditions), thus making comparisons very difficult. Finally, the financial considerations receive little attention; yet they are of paramount importance in any work on pollution control.

A careful study with a systematic approach for generalization must be designed. Such a study will compare and document results about the most promising mitigation techniques.

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Section 9.0

THE MAGNITUDE OF THE FORMALDEHYDE PROBLEM

Section 9.0

THE MAGNITUDE OF THE FORMALDEHYDE PROBLEM

The magnitude of the formaldehyde problem in mobile homes is composed of two (multiplicative) elements: (1) the incidence and (2) the severity of health effects. Section 6.0 of this report described the range of severity of the health effects; this section focuses on the incidence.*

In order to obtain some measure of the incidence of these formaldehyde problems, various Government Agencies and private organizations were contacted--including State Administrative Agencies (SAAs), consumer agencies, state departments of health, mobile-home manufacturers and dealers. With the exception of four state agencies in Oregon, Washington, Wisconsin and Minnesota, the cases of formaldehyde problems reported were few in number. For example, the SAAs, which were established to receive and respond to consumer complaints, averaged less than five formaldehyde complaints per state per year. The mobile-home manufacturers and dealers, and their associations, reported even fewer cases annually. Similarly, the Consumer Product Safety Commission had filed reports of only about 25 formaldehyde problems nationally per year. The results of these contacts are summarized in Table 9-1.

The information provided by these contacts indicated that the formaldehyde problem is nationwide. However, the data collected from these

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* In this chapter, the data and analysis refer only to the formaldehyde associated with the structure of the mobile home as originally manufactured. Because no new mobile homes have been constructed since June 1976 with urea-formaldehyde foam wall insulation, the effects of urea-formaldehyde foam wall insulation have been specifically excluded in the following analysis.

Table 9-1. Organizations Contacted to Obtain Mobile Home Formaldehyde Data

I. Federal Government

Agency/Department	Name	Phone No.	Comments Avg. No. of Formaldehyde Complaints per Year
Consumer Product Safety Commission (CPSC)			
Bethesda (Main Office)	CPSC files		25
	Nick Marchica	(301) 492-6453	hearing on UF foam
	A.G. Ulsamer	(301) 492-6957	supplied contacts
	Chuck Smith	(301) 492-6962	supplied contacts
Atlanta Regional Office	Marta Knowthen	(404) 881-2231	supplied contacts
	Leslie Pounds	(404) 881-2231	10
Dallas Regional Office	Larry Blend	(214) 767-0841	10
Environmental Protection Agency (EPA)			
Office of Toxic Substances	Dr. Kuchkuda	(202) 755-2110	supplied contacts
Federal Trade Commission (FTC)			
Bureau of Consumer Protection	Art Levin	(202) 523-1642	supplied contacts
Seattle Regional Office	Jerry Brown	(206) 442-4655	supplied contacts
Department of Housing and Urban Development (HUD)	T. Gottesman	(202) 755-6584	supplied contacts

II. State Government

Agency/State	Name	Phone No.	Comments Avg. No. of Formaldehyde Complaints Per Year
State Administrative Agencies			
Alabama	John Robison	(205) 832-5844	6
Arizona	Mr. Wolfe	(602) 255-4072	6
Arkansas	Mitchell Baker	(501) 371-1641	2
California	Russel Bahr	(916) 445-9471	refer complaints to HUD
Colorado	Leslie Tingle	(303) 839-2033	25
Florida	Orville Cummings	(904) 487-2118	2
Georgia	Bobby Wright	(404) 656-2064	5
Idaho	Ed Bendocchi	(208) 384-2327	1
Indiana	Harold Bailey	(317) 282-1437	8
Iowa	Don Appell	(515) 281-3807	5
Kentucky	C. Robinson	(502) 564-3626	25
Louisiana	Clint Dobson	(504) 925-4917	1

(continued)

Table 9-1. (continued)

Maryland	Willard Bryant	(301) 269-2701	3
Massachusetts	Paulene Stanton	(617) 727-6916	no complaints
Michigan	Barb Freeman	(517) 322-1701	4
Minnesota	Richard Hauck	(612) 296-4628	refer to Health Dept.
Mississippi	Jerry Black	(601) 354-6304	2
Missouri	Ed Cline	(314) 751-2557	6
Nebraska	Ron Wolf	(402) 471-2541	4
Nevada	Wayne Tetroult	(702) 885-4298	no complaints
New Jersey	Joseph Schaffram	(609) 292-6415	1
New Mexico	John Wilson	(505) 827-5571	no complaints
New York	Bennett Selekoff	(212) 488-7080	very few
North Carolina	O. Tharrington	(919) 733-3901	no complaints
Oregon	Wes Galloway	(503) 378-3986	refer to Health Dept.
Pennsylvania	James Shields	(717) 787-9682	4
Rhode Island	Joseph Cirillo	(401) 277-3033	no complaints
South Carolina	Rick Howell	(803) 758-2941	3
South Dakota	Al Christie	(605) 773-3696	no complaints
Tennessee	David Borum	(615) 741-2981	1
Texas	Mike Alexander	(512) 475-5712	very few
Utah	Ted Himstreet	(801) 533-4242	2
	Ed Short	(801) 533-4242	supplied contacts
Virginia	Mr. Early	(804) 786-4751	1
Washington	James Louvier	(206) 464-6580	50
Wisconsin	John Eagen	(608) 266-3151	refer to Health Dept.

State Health Depts.

California	Dr. Holk	(714) 784-1860	20
Florida	Ken Widergren	(904) 488-4070	supplied contacts
Massachusetts	Jerry Parker	(617) 727-2660	supplied contacts
Minnesota	Laura Oatman	(612) 296-5219	special study (145)
New Jersey	Dr. Thun	(609) 292-4046	supplied contacts
New York	Dr. Stasiuc	(518) 474-4242	supplied contacts
Oregon	L.P. Williams	(503) 229-5599	special study (60)
Washington	Jim White	(206) 753-5961	supplied contacts
Wisconsin	Mary Ann Woodbury	(608) 266-1550	special study (65)

Other State Agencies

Florida Cons. Prot. Bureau	Tom Pflaum	(904) 488-8916	no complaints
Mass. Cons. Prot. Office	Barbara McGinnis	(617) 727-7780	supplied contacts
Mass. Mobile Home Commission	Clark Taylor	(617) 287-1900	supplied contacts
N.J. Dept. of Envir. Prot.	Sid Gray	(609) 292-9002	supplied contacts
Wisconsin Dept. of Industry, Labor, & Human Relations	Richard Meyers	(608) 266-3080	supplied contacts

(continued)

Table 9-1. (continued)

III. Manufacturers

Company	Name	Phone	Comments Avg. No. of Formaldehyde Complaints per Year
Brigadier Industries Corp.	H.B. Moorehead	(404) 595-1507	2 to date
Champion Home Builders	Lou Baliua	(313) 796-2211	5
Fleetwood Enterprises	Pat Hayes	(800) 854-4755	no comment (under litigation)
Guerdon Industries (Corp. HQ)	Mr. Calzaretta	(502) 425-8080	supplied contacts
Atlantic Division	Hoke Williams	(912) 285-8930	very few
Cabot, AP plant	Butch Smith	(501) 843-3581	3 to date
Central Division	Larry Dirck	(501) 758-5757	none documented
Manila, AR plant	Pat Parker	(501) 561-4443	none documented
Marshfield Homes		(713) 387-2551	1.25% of homes sold
Redman Homes, Inc.	Jack Henry	(214) 350-3761	supplied contacts
Schult Homes Corp. (Corp. HQ)	Mike Hopkins	(219) 825-5881	supplied contacts
Redwood Falls, Mn. Div.	Dave Baker	(507) 637-3555	2 to date
Skyline Corp.	Jean Gassere	(219) 294-6521	supplied contacts
Tidwell Industries (Corp. HQ)	Bristol Haughton	(205) 486-9221	1 to date
Dolphin Homes Division	Fred Cooper	(205) 486-7511	1
LaSalle/Madrid Homes Div.	Scratch Barkly	(601) 837-8131	no complaints
Marion Homes Division	Mike Long	(205) 486-5721	2
Tidwell Homes of N.C. Div.	Dave Patterson	(704) 279-5531	4
Wick Building Systems	Bruce Griffin	(608) 274-7640	supplied contacts
Zimmer Homes Corp.	Dir. of Engrg.	(305) 943-7600	very few to date

IV. Dealers

State/name	Name	Phone	Comments Avg. No. of Formaldehyde Complaints per Year
Florida Dealers			
C.J. Stoll, Inc.	Steve Weiss	(813) 238-3864	no problem
Hawthorne at Leesburg	Dan Gordon	(904) 787-1000	no problem
Mel Riff Mobile Homes	Mr. Houser	(305) 245-5125	no problem
Mustang Mobile Homes	Terry Devilling	(904) 737-4366	no problem
Riley Mobile Home Sales	Peggy Whitehurst	(813) 621-6555	very few to date
Ronnie's Mobile Homes	Ron Kool	(305) 632-8801	no problem
Sam's Mobile Homes	Dick Myers	(813) 688-8497	no problem
Indiana Dealers			
ABC Mobile Homes	Jack Vaugn	(317) 447-6993	very few to date
D&J Mobile Homes	Dean Lester	(317) 935-2055	several
Eastview Mobile Homes Park	Joseph Jackaway	(812) 384-3521	virtually none
Hilltop Trailer Sales	George Dunn	(812) 424-1887	no problem
KBK Mobile Home Center	Dennis Krejci	(219) 838-7086	12
Paradise Park	Mary Lou Vargo	(312) 758-4173	no problem
Tops Mobile Home Center	Larry Kantz	(219) 264-3171	10-12
Texas Dealers			
Big B's Mobile Homes	Bill Bevel	(817) 838-3811	no problem

(continued)

Table 9-1. (concluded)

V. Manufacturer and/or Dealer Associations

Association	Name	Phone	Comments Avg. No. of Formaldehyde Complaints per Year
California Dealers Assoc.	Ray Ashwell	(916) 446-4024	very few to date
Dealers National Federation	Mike Lemov	(202) 785-4800	supplied contacts
Florida Mfgd Housing Assoc.	Bob Hugli	(904) 222-4014	no problem
Indiana Mfgd Housing Assoc.	Dan Gilligan	(317) 247-6258	no problem
	Holt Blumgrin	(317) 247-6258	no problem
Manufactured Housing Inst.	George Renault	(703) 974-6620	very few to date
Texas Dealers Assoc.	Will Ehrle	(512) 45901221	a couple/year
Washington Mfgd Housing Assoc.	Bob Copeland	(206) 357-5650	several

VI. Occupant and/or Consumer Associations

Association	Name	Phone	Comments Avg. No. of Formaldehyde Complaints per Year
American Mobile Home Assoc.	Earnest White	(303) 232-6333	very few to date
Fed. of Mobile Home Owners of Florida	William White	(813) 52704142	25
Golden State Mobile Home Owners League (Calif.)	John Santner	(408) 438-2358	very few to date
Michigan Mobile Home Owners Assoc.	Robert Myers	(313) 495-0011	5
Mobile Home Owners of America	John Jensen	(206) 485-4343	very few to date
Texas Consumer Association	Jim Boyle	(512) 477-5791	supplied contacts
Texas Mobile Home Owners Assoc.	Vic Salerno	(512) 696-7952	no problem

VII. Other Groups Contacted

Organization	Name	Phone	Comments Avg. No. of Formaldehyde Complaints per Year
Center for Auto Safety	Kathy Meyer	(202) 659-1126	supplied contacts
Harvard School of Public Health	John Spengler	(617) 732-1255	supplied contacts
Mead & Hunt Consulting Corp.	Jim Seymour	(608) 233-9706	monitoring levels
National Particleboard Assoc.	C. Morschauser	(301) 587-2204	supplied contacts
University of Iowa	Keith Long	(319) 353-4872	UF foam study/DOE
University of Washington	Peter Breysse	(206) 543-4252	special study (100)
National Forest Product Assoc	Dr. John Festa	(202) 797-5800	supplied contacts
National Academy of Science (NAS)	Dr. J.A. Frazier		
Oak Ridge National Lab (ORNL)	Dr. P.J. Walsh		supplied contacts
Formaldehyde Institute	Kip Howlett		supplied contacts

contacts were insufficient to assess the incidence of the problem nationally. Three factors accounted for the absence of a valid national data base. First, no one agency was responsible for the collection of all formaldehyde complaints. Second, a national, systematic sampling program did not exist. Finally, there was no attempt to inform mobile home owners across the country of the possibility of formaldehyde exposure and resulting symptoms. Therefore, to evaluate the incidence of the formaldehyde problem nationally, data were obtained from a few states that had attempted to overcome these barriers, and their results were extrapolated nationally.

The four states mentioned previously (Oregon, Washington, Wisconsin, and Minnesota) were the only ones to attempt to implement a systematic reporting or sampling program to address the formaldehyde problem in mobile homes. In Oregon, whose data have yet to be received by T+E, the state health division sent out questionnaires to randomly selected mobile homes within the state. The questionnaires asked occupants about health problems that the occupants felt were associated with their mobile homes, symptoms of these health problems, and whether the symptoms persisted after leaving the mobile home. Two sets of questionnaires were sent out--one set was sent to occupants of a humid region within the state, and the other set was sent to occupants of a dry region within the state. Preliminary analysis by the Oregon State Health Department revealed little difference between the responses of the two data sets. Further analysis will be conducted on this sample after it is received by T+E. In the remaining three states efforts of varying degrees were made to:

- Have all state agencies refer mobile home formaldehyde complaints to one source--the State Health Department in both Minnesota and Wisconsin, and Peter Breysse (University of Washington) in Washington

- Inform both physicians and mobile home occupants of their existence as a state clearinghouse for formaldehyde complaints and formaldehyde information
- Educate the public to identify formaldehyde symptoms
- Weed out occupants whose symptoms do not correspond to the symptoms usually attributed to formaldehyde exposure.

Sections 9.1, 9.2, and 9.3 will discuss the specific results obtained from the Washington, Wisconsin, and Minnesota data. The final section (9.4) will analyze the similarities and differences identified among these three data sets and, using these data sets, attempt to estimate the magnitude of the formaldehyde problem in mobile homes nationally.

9.1 MOBILE HOME FORMALDEHYDE DATA FROM WASHINGTON

At the University of Washington, Peter Breysse has collected 187 mobile home formaldehyde cases over the past 2 years. As demonstrated in Table 9-2, the number of reported formaldehyde problems in Washington were negatively correlated with the age of the mobile home: 59 percent of the samples were less than 2 years old, and 75 percent of the samples were less than 3 years old. The average for the sample was approximately 2 years. As displayed in Table 9-3, 94 percent of the samples reported formaldehyde levels below 1.0 ppm and 56 percent below 0.4 ppm, but only 5 percent of the samples reported levels below 0.1 ppm. The average level sampled was 0.6 ppm. Figure 9-1 indicates that the formaldehyde levels for the samples are negatively related to the age of the mobile home. Although several functional forms were tried to relate the level of formaldehyde and the age of the mobile home, none satisfactorily fit the empirical data set.

Table 9-2. Washington: Age Distribution of Mobile Homes in Sample

Age of Mobile Home	Frequency	Percent	Cumulative Percent
≤ 6 mo.	23	13.3	13.3
>6 mo - 1 yr.	31	17.9	31.2
>1 yr - 2 yr	48	27.7	58.5
>2 yr - 3 yr	29	16.8	75.7
>3 yr - 4 yr	14	8.1	83.8
>4 yr - 5 yr	8	4.6	88.4
>5 yr	20	11.6	100.0
Missing	14	Missing	Missing
	187	100.0	

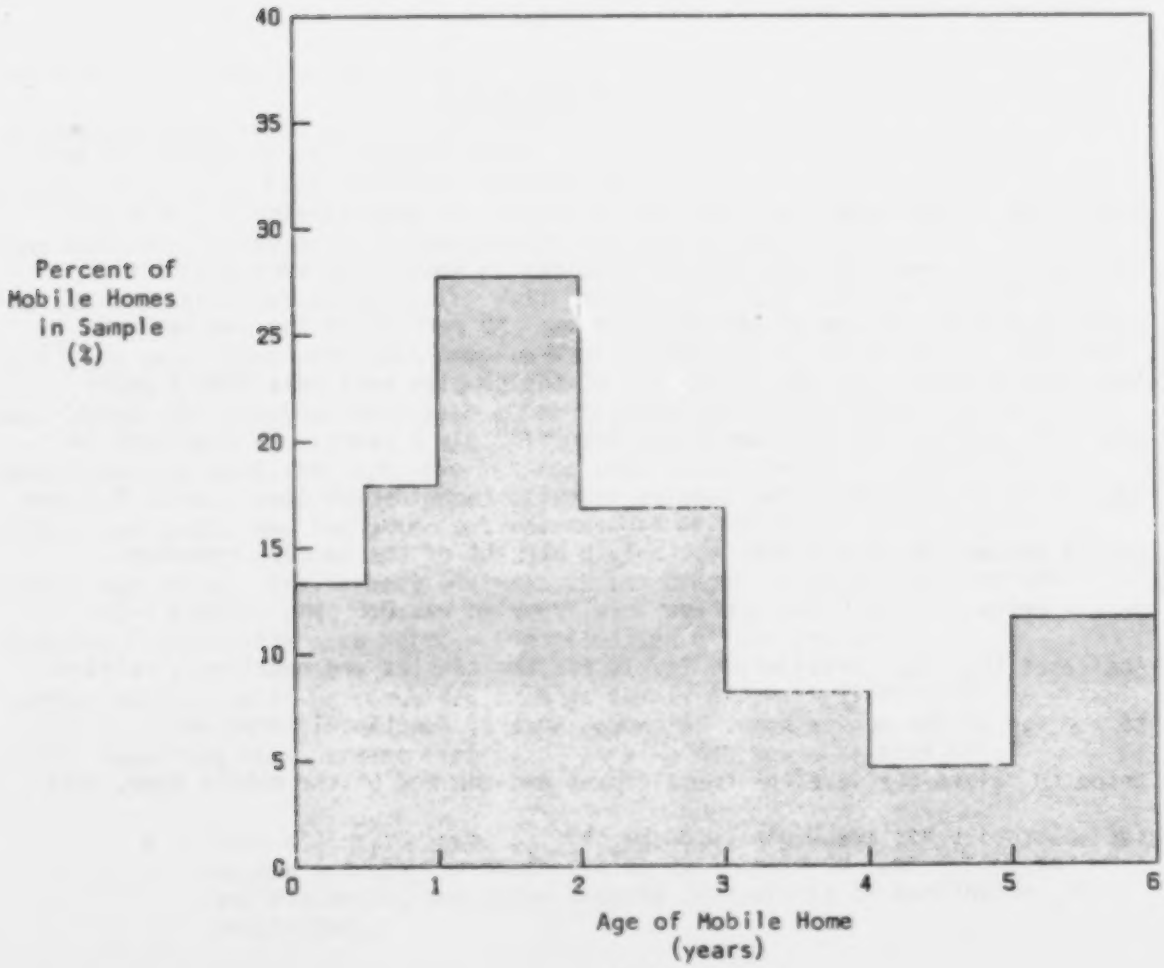
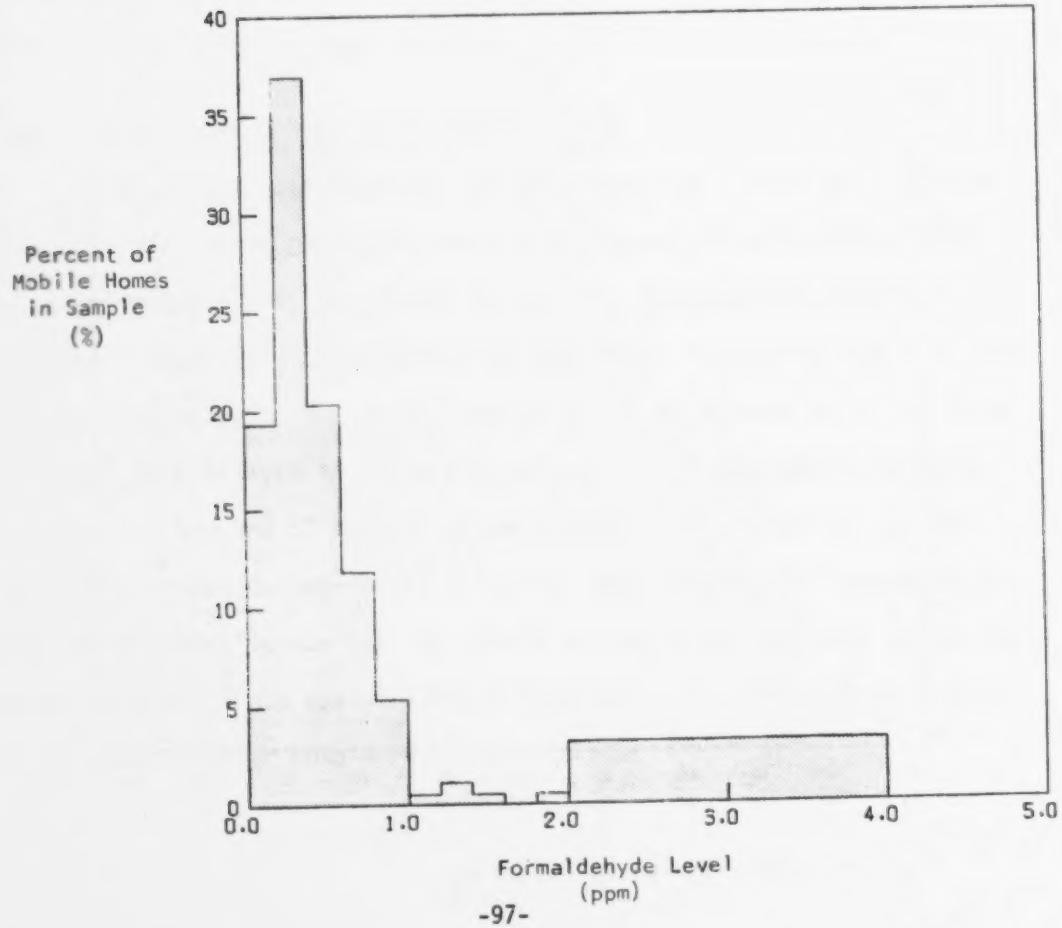


Table 9-3. Washington: Distribution of Formaldehyde Levels in Sampled Mobile Homes

Formaldehyde Levels	Frequency	Percent	Cumulative Percent
≤ .20	36	19.4	19.4
.21- .40	69	36.9	56.3
.41- .60	38	20.3	76.6
.61- .80	22	11.8	88.4
.81-1.00	10	5.3	93.7
1.01-1.20	2	1.1	94.8
1.21-1.40	2	1.1	95.9
1.41-1.60	1	.5	96.4
1.61-1.80	0	0	96.4
1.81-2.00	1	.5	96.9
≥ 2.01	6	3.1	100.0
	187	100.0	



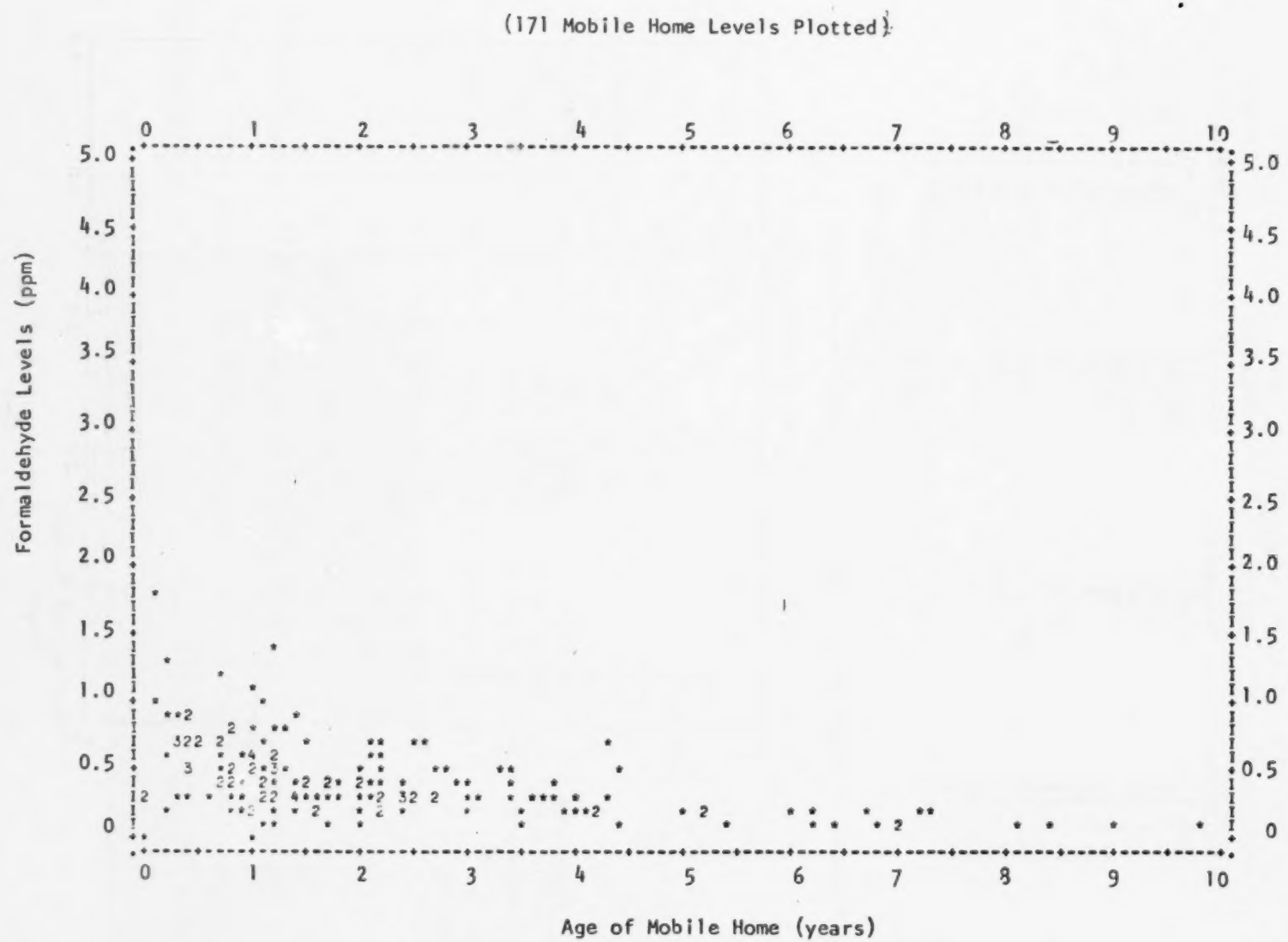


Figure 9-1. Washington: Formaldehyde Level vs. Mobile Home Age.

Several limitations of the Washington sample should be noted. First, the measurement technique utilized only one impinger. Although the measurements were adjusted (by T+E) for 100 percent efficiency and are scientifically valid, the recommended NIOSH method was not employed by Peter Breysse. Second, data-gathering procedures were not based on physician referral of patients with formaldehyde symptoms. For this reason, it is possible that homes were sampled in which the occupants were not suffering from adverse health effects due to formaldehyde exposure. Finally, although the formaldehyde problem has received a great deal of attention in Washington, it is unclear what proportion of the mobile home population was sufficiently informed to associate their symptoms with formaldehyde exposure and to report their formaldehyde complaints to Peter Breysse.

9.2 MOBILE HOME FORMALDEHYDE DATA FROM WISCONSIN

In Wisconsin, the State Health Department has collected data from 47 cases of formaldehyde complaints over approximately 2 years (1978-1979). As indicated in Table 9-4, the number of reported formaldehyde problems in Wisconsin were negatively correlated with the age of the mobile home: 60 percent of the samples were less than 1 year old, and 80 percent were less than 2 years old. As displayed in Table 9-5, 85 percent of the sample reported levels below 1.0 ppm and 51 percent below 0.4 ppm. Only 6 percent of the sample reported formaldehyde levels below 0.1 ppm. Figure 9-2 demonstrates that the formaldehyde levels for the sample are negatively related to the age of the mobile home. Once again, various functional relationships were tried to fit the data; however none were satisfactory.

Table 9-4. Wisconsin: Age Distribution of Mobile Homes in Sample

Age of Mobile Home	Frequency	Percent	Cumulative Percent
≤ 6 mo.	8	20.0	20.0
>6 mo - 1 yr.	16	40.0	60.0
>1 yr - 2 yr	8	20.0	80.0
>2 yr - 3 yr	2	5.0	85.0
>3 yr - 4 yr	0	0	85.0
>4 yr - 5 yr	1	2.5	87.5
>5 yr	5	12.5	100.0
Missing	7	Missing	Missing
	47	100.0	

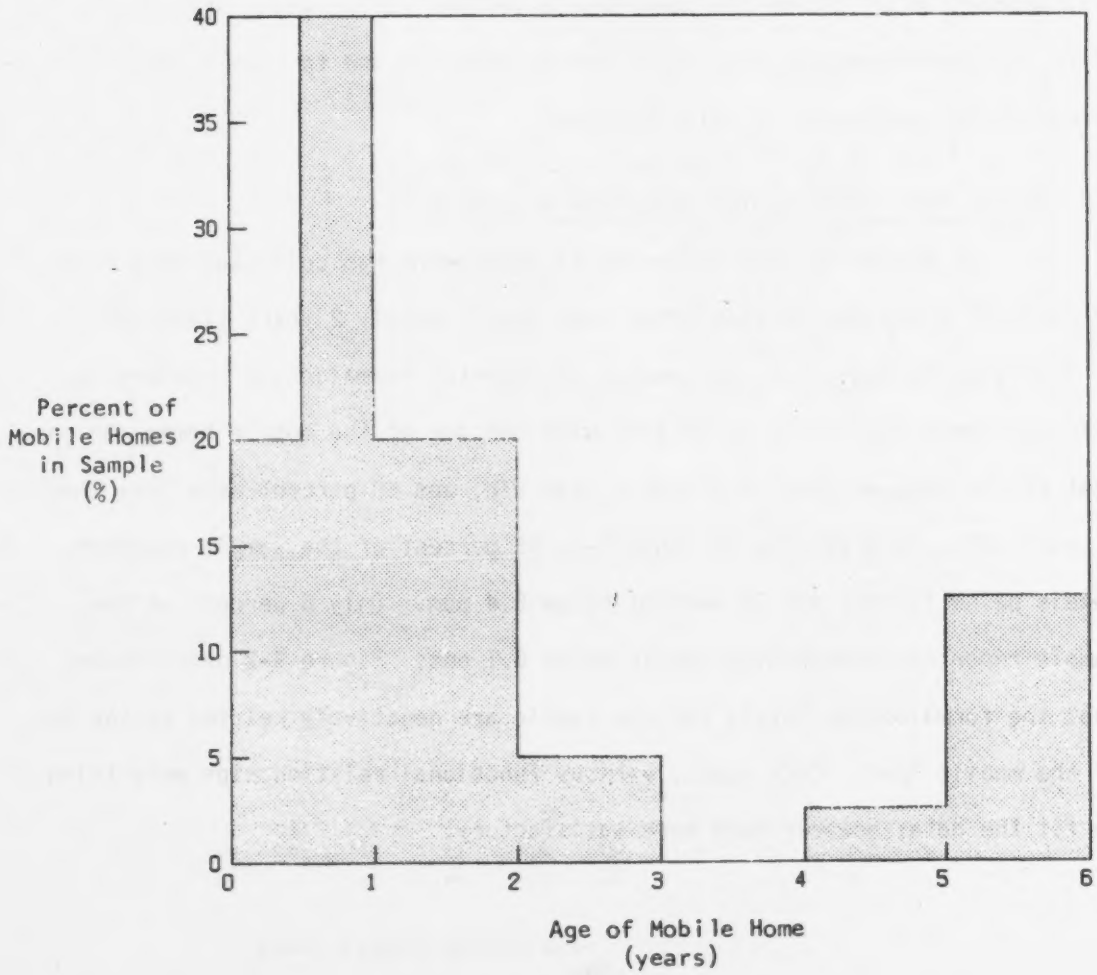
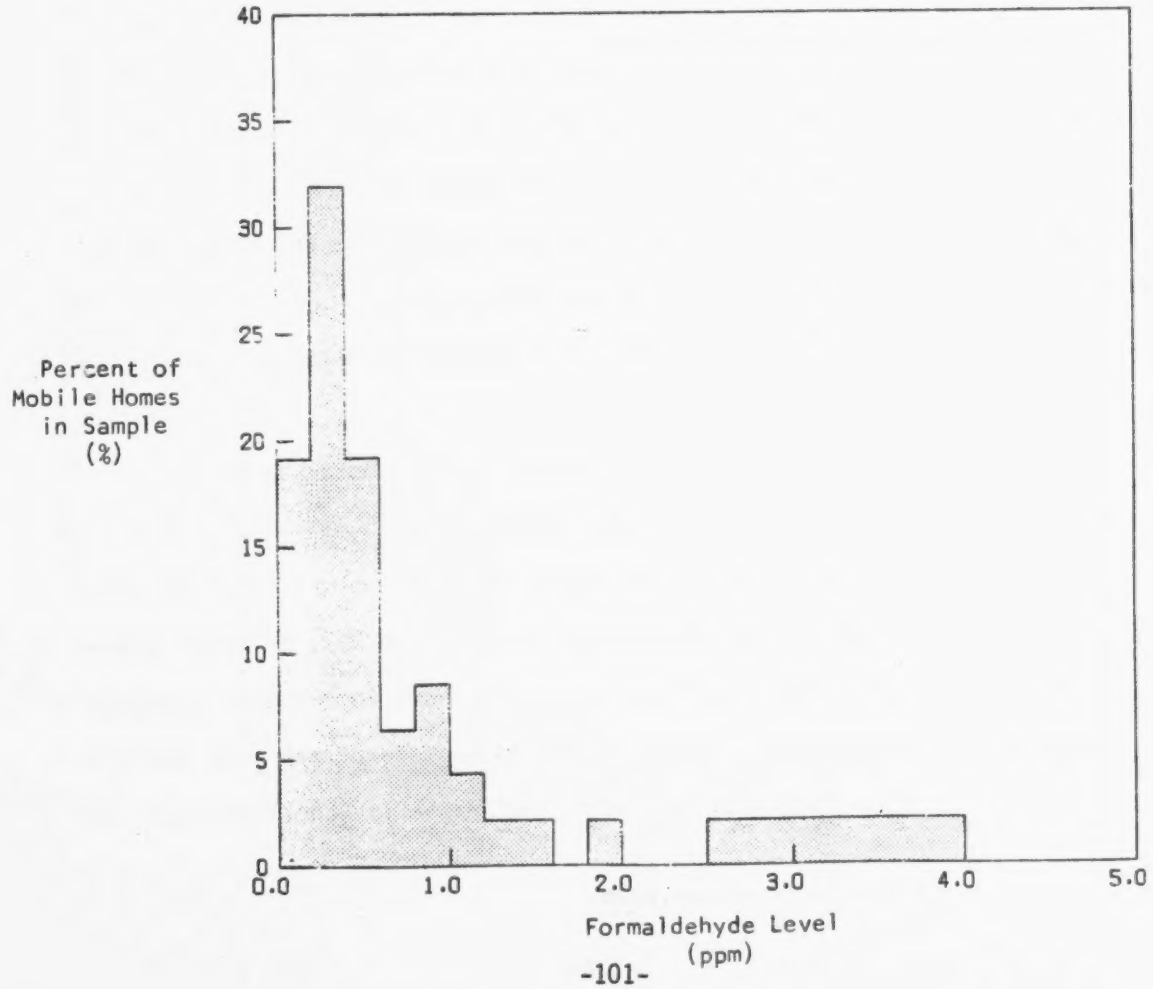


Table 9-5. Wisconsin: Distribution of Formaldehyde Levels in Sampled Mobile Homes

Formaldehyde Levels	Frequency	Percent	Cumulative Percent
≤ .20	9	19.1	19.1
.21- .40	15	31.9	51.0
.41- .60	9	19.2	70.2
.61- .80	3	6.4	76.6
.81-1.00	4	8.5	85.1
1.01-1.20	2	4.3	89.4
1.21-1.40	1	2.1	91.5
1.41-1.60	1	2.1	93.6
1.61-1.80	0	0	93.6
1.81-2.00	1	2.1	95.7
2.01-2.50	0	0	95.7
2.51-3.00	1	2.1	97.8
3.01-4.00	1	2.1	100.0
>4.0	0	0	100.0
	47	100	



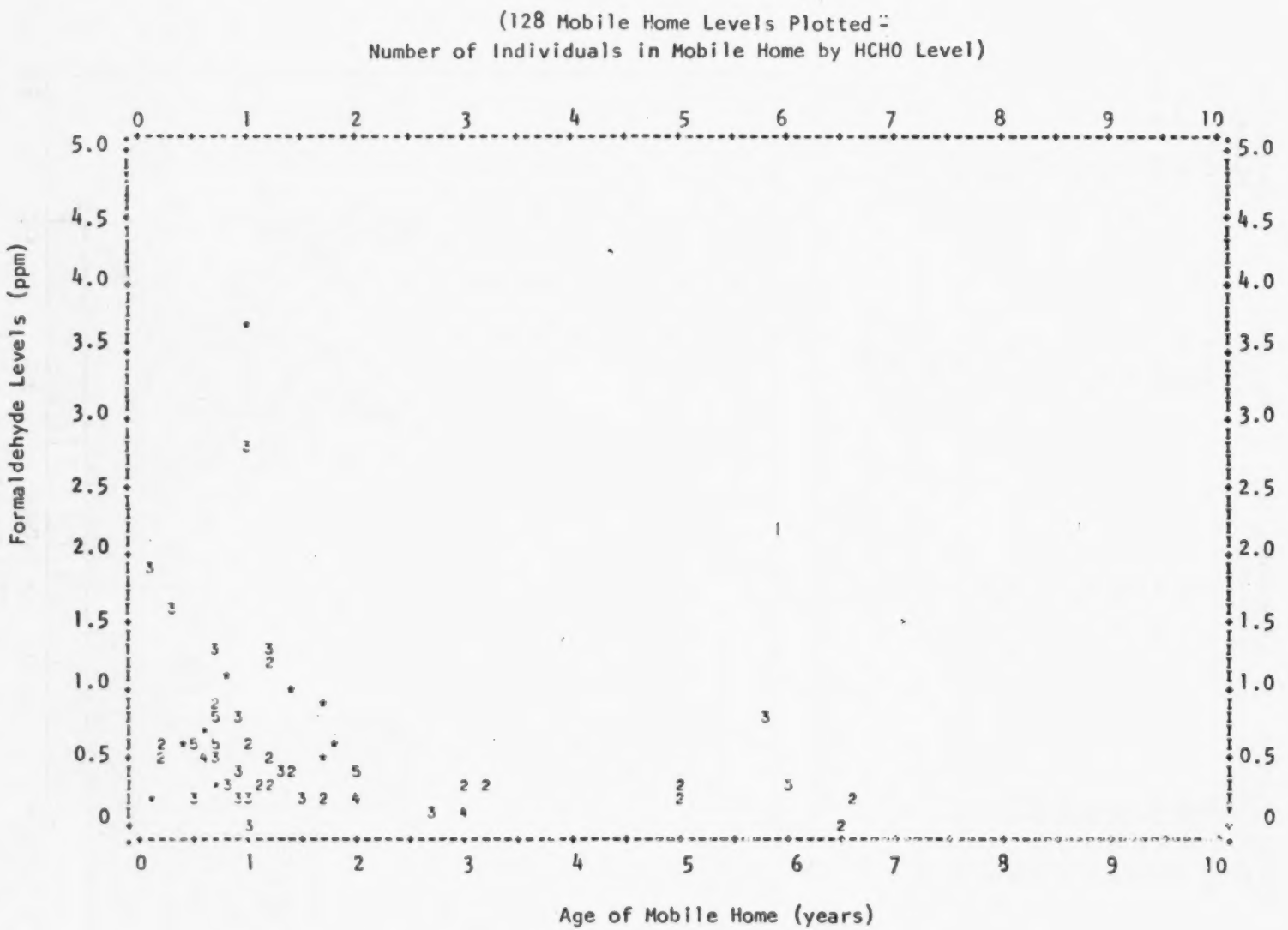


Figure 9-2. Wisconsin: Formaldehyde Level vs. Mobile Home Age.

The Wisconsin Department of Health and Social Services also conducted a pilot project, under a grant from the U.S. Environmental Protection Agency, to measure the formaldehyde level in a random sample of 65 mobile homes. The mean formaldehyde level for the 65 randomly selected homes was 0.24 ppm, with a standard deviation of 0.23 ppm, as compared to a mean of 0.66 ppm in the complaint homes. However, since formaldehyde levels appear to decay over time in a mobile home, the more relevant question is the mean formaldehyde level in randomly sampled and complaint homes of a given age. The mean formaldehyde level in randomly sampled homes less than 2.5 years of age was 0.53 ppm; from 2.5 to 7.5 years, 0.20 ppm; from 7.5 to 10 years, 0.15 ppm; and over 10 years, 0.10 ppm. These figures compare with formaldehyde levels in complaint homes of 0.71 ppm for mobile homes less than 2 years of age; 0.18 ppm for 2 to 5 years; and 0.24 ppm for over 5 year old homes. The estimates of formaldehyde levels for the complaint homes over 2 years of age must be treated with caution since the sample size was small and the standard deviations were large in relation to mean values. When adjusted for age of mobile home, the formaldehyde levels in randomly sampled and complaint mobile homes are not substantially different.

In addition to the information presented above, the State of Wisconsin collected data from complaint homes concerning the formaldehyde symptoms experienced by the mobile home occupants. In order of response, the most widely reported symptoms were eye irritation, upper respiratory tract irritation, headache, respiratory difficulty, and diarrhea (Table 9-6). Preexisting problems were negligible, except for allergies (approximately 25 percent of the respondents had allergies before moving into their homes).

Table 9-6. Wisconsin: Symptoms Experienced by Mobile Home Occupants

Symptom	Percent of Occupants Experiencing Symptoms: Yes (%)	No (%)
eye irritation	68	32
upper respiratory tract irritation	64	36
headache	34	66
respiratory difficulty	29	71
restlessness/tiredness	29	71
diarrhea	15	85
nausea	14	86
vomiting	11	89
asthma	4	96

Pre-existing Problem	Percent of Occupants with a Pre-existing Condition: Yes (%)	No (%)
pre-existing allergies	24	76
other pre-existing conditions	8	92
pre-existing respiratory problem	8	92
pre-existing cardiac problem	7	92

Several limitations of the Wisconsin sample should be noted. First, data gathering procedures are not necessarily based on physician referrals; the general public may call up and request that their home be sampled, but the health department does require preliminary screening of these calls. The screening consists of questions such as, "What are your symptoms?" and "Why do you think these symptoms are related to your home?" Second, it is unclear what proportion of Wisconsin physicians have not been informed of the Department of Health project and are therefore not referring their patients with formaldehyde symptoms to the Department.* For instance, if a significant percentage of Wisconsin physicians are not identifying patients with formaldehyde symptoms and referring them to the Department of Health, then the incidence of formaldehyde problems reported here will be significantly underestimated. Third, it is unclear what proportion of the patients with formaldehyde symptoms are actually suffering from formaldehyde exposure.** Finally, it is not apparent how well informed the public is about the health department's program. However, since the only formal information dissemination was a single news release, it is likely that most mobile home occupants are unaware of the formaldehyde program.

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* Approximately 75 percent of Wisconsin's physicians received one newsletter concerning the project; whether this newsletter provided sufficient exposure for these physicians to identify and report formaldehyde symptoms is open to conjecture.

** However, an experienced physician has evaluated each case, usually after personally discussing the case with the family physician, and has concluded whether formaldehyde was the probable cause of the symptoms. This information had not been coded at the time T+E received the data from Wisconsin.

9.3 MOBILE HOME FORMALDEHYDE DATA FROM MINNESOTA

In Minnesota, where programs have been instituted to inform physicians and the public about potential formaldehyde symptoms, the state health department has sampled 109 mobile homes during a 9-month period. As indicated in Table 9-7, there is a negative correlation between the number of reported formaldehyde problems in Minnesota and the age of the mobile home: 60 percent of the homes sampled were less than 2 years old, and 73 percent of the homes were less than 3 years old. However, as displayed in Table 9-8, 83 percent reported levels below 1.0 ppm and 50 percent below 0.4 ppm. Only 10 percent of the homes sampled reported formaldehyde levels less than 0.1 ppm. Figure 9-3 demonstrates that the formaldehyde levels for the sample are negatively related to the age of the mobile home. Once again, no functional relationship was found to fit the data.

One distinguishing feature of the Minnesota program is the detailed questionnaire used in addition to the field measurements. One of the questions was, "When was the odor first noticed?" The response indicated that in 85 percent of the homes a peculiar odor was noticed, and in 75 percent of the homes the odor was noticed within the first month after moving in.

In order to derive a crude estimate of whether age of the occupant or the formaldehyde level influenced the severity of the symptoms, we used the number of symptoms reported as a proxy for the severity of the case. The analysis of the occupant symptoms failed to establish a clear relationship between the average number of symptoms reported and the formaldehyde level and the occupant's age (see Tables 9-9 and 9-10). In order of response, the most widely reported symptoms were eye irritation, nose and throat irritation,

Table 9-7. Minnesota: Age Distribution of Mobile Homes in Sample

Age of Mobile Home	Frequency	Percent	Cumulative Percent
≤ 6 mo.	11	10.1	10.1
>6 mo - 1 yr.	29	26.6	36.7
>1 yr - 2 yr	26	23.9	60.6
>2 yr - 3 yr	14	12.8	73.4
>3 yr - 4 yr	7	6.4	79.8
>4 yr - 5 yr	6	5.5	85.3
>5 yr	16	14.7	100.0
	109	100.0	

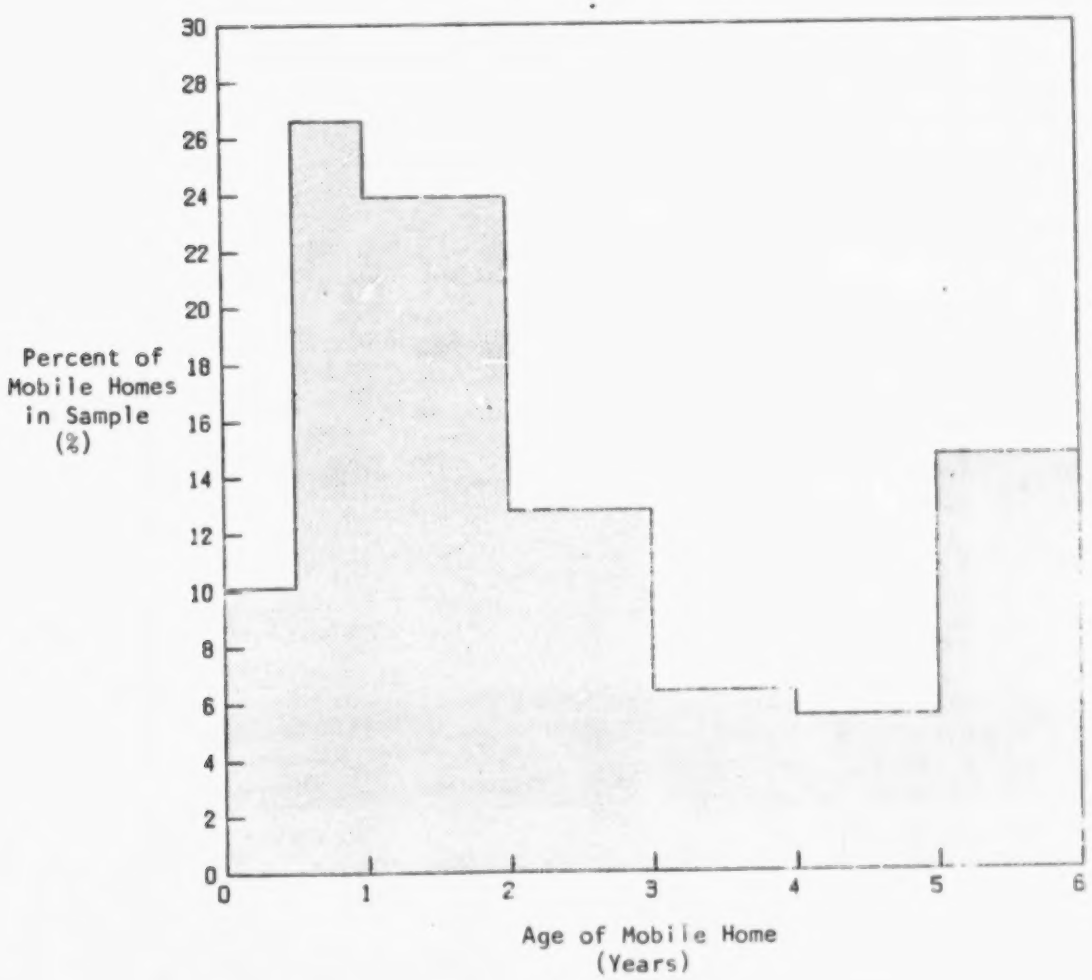
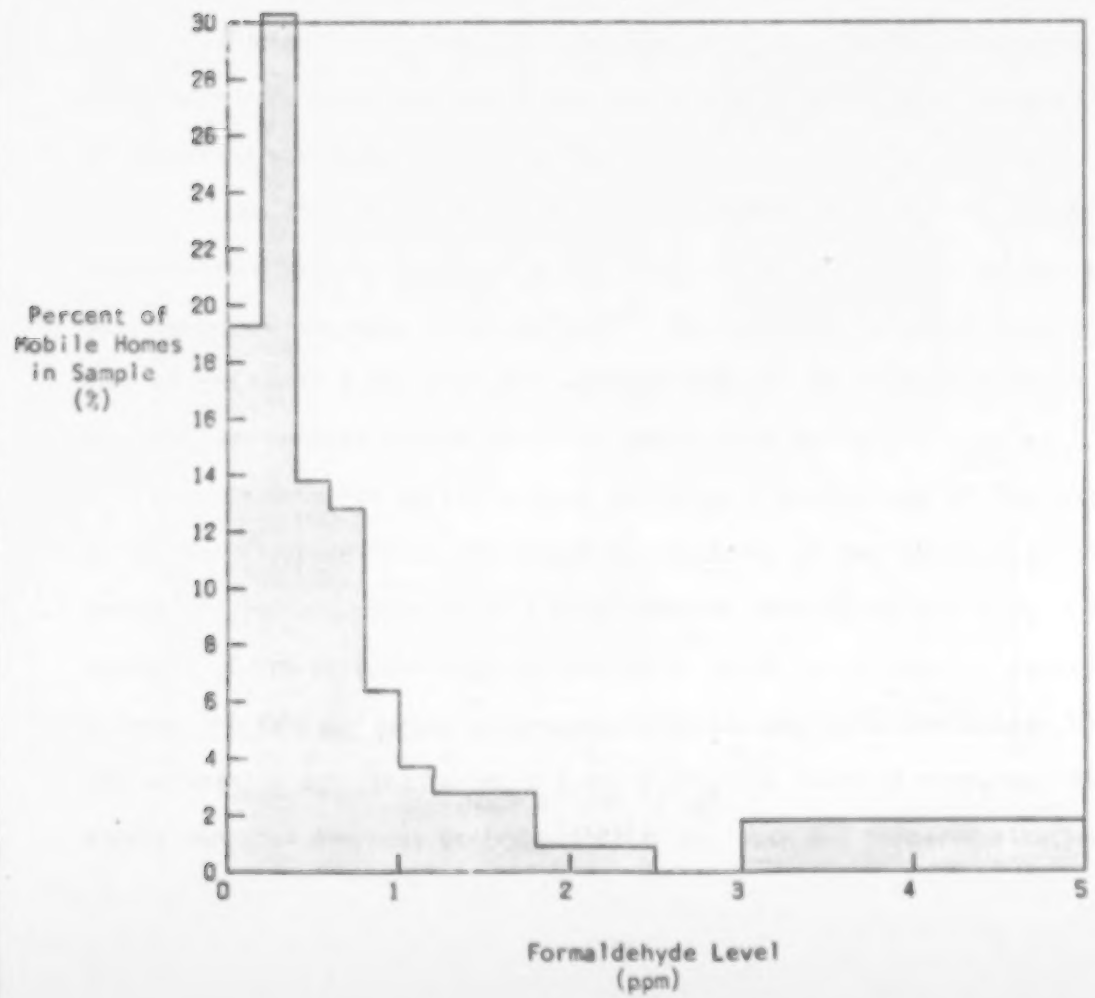


Table 9-8. Minnesota: Distribution of Formaldehyde Levels in Sampled Mobile Homes

Formaldehyde Levels	Frequency	Percent	Cumulative Percent
≤ .20	21	19.3	19.3
.21- .40	33	30.3	49.6
.41- .60	15	13.8	63.4
.61- .80	14	12.8	76.2
.81-1.00	7	6.4	82.6
1.01-1.20	4	3.7	86.3
1.21-1.40	3	2.8	89.1
1.41-1.60	3	2.8	91.9
1.61-1.80	3	2.8	94.7
1.81-2.00	1	0.9	95.6
2.01-2.50	1	0.9	96.5
2.51-3.00	0	0.0	96.5
3.01-4.00	2	1.8	98.3
> 4.0	2	1.7	100.00
	109	100.0	



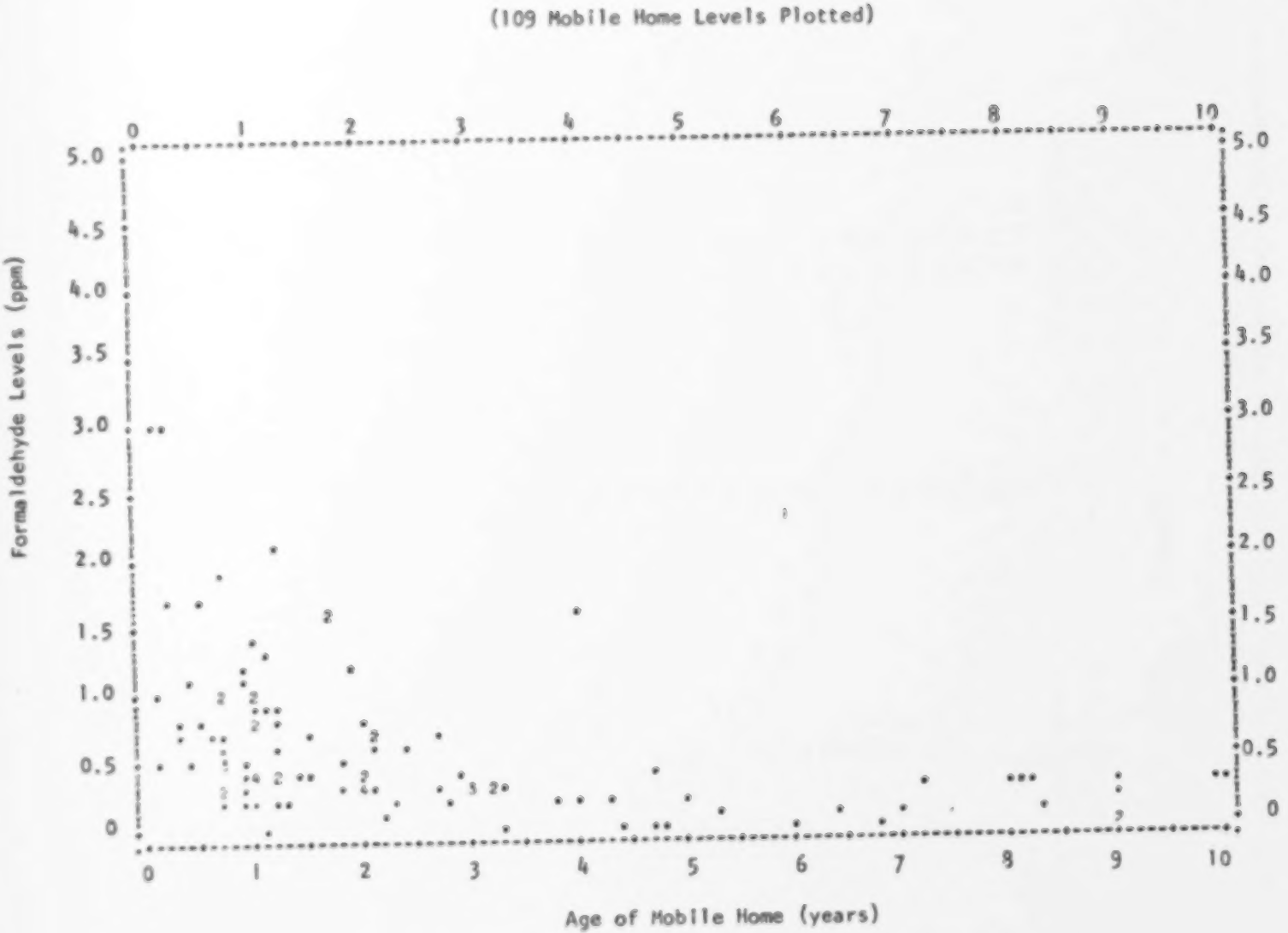


Figure 9-3. Minnesota: Formaldehyde Level vs. Mobile Home Age.

Table 9-9. Minnesota: Number of Symptoms Experienced by Mobile Home Occupants for Various Formaldehyde Levels

Formaldehyde Level (ppm)	Number of Responses	Average Number of Symptoms Reported
.09	37	4.73
.1 - .20	29	5.55
.21 - .30	60	5.75
.31 - .40	49	3.73
.41 - .50	28	4.64
.51 - .60	10	3.90
.61 - .80	44	4.84
.81 -1.00	19	4.74
1.01 -1.20	15	6.27
1.21 -1.40	8	5.38
1.41 -1.60	9	4.22
1.61 -1.80	7	3.86
1.81 -2.0	4	4.00
2.01 -2.5	2	4.00
2.51 -3.00	0	--
3.01 -4.0	3	3.67
4.0	6	5.17
Total	330	4.86

Table 9-10. Minnesota: Number of Symptoms Experienced by Mobile Home Occupants

Occupant Age	Number of Responses	Average Number of Symptoms Reported
2	95	4.56
2 - 5	36	5.36
6 - 9	11	7.55
10 - 14	2	4.50
15 - 19	9	5.89
20 - 24	71	4.75
25 - 34	71	4.37
35 - 44	10	4.80
45 - 54	9	4.78
55 - 65	12	6.17
65	4	5.25
Total	330	4.86

runny nose, cough, and headache, and the clear majority of the respondents said that their symptoms did not persist after leaving the home (see Table 9-11). Approximately 53 percent of the occupants had five or more symptoms and 77 percent had three or more symptoms (see Table 9-12).

Another method for identifying the influence of formaldehyde levels on occupant symptoms (i.e., whether a dose-response relationship exists) is to examine the percentage of occupants with a given symptom as a function of the formaldehyde level. Table 9-13 presents percentage figures for four formaldehyde symptoms: eye irritation, nose and throat irritation, headaches, and frequent colds. Note that with the exception of frequent colds, there appears to be a clear dose-response relationship in terms of percentage of occupants reporting symptoms for less than and greater than 0.5 ppm. On the other hand, the largest percentage of complaints was consistently between 1.0 and 2.0 ppm, with formaldehyde levels above 2.0 ppm associated with a lower percentage of occupants reporting symptoms.

The detailed reporting of observed formaldehyde symptoms for all mobile home occupants in the Minnesota sample permitted us to test whether hypersensitivity to formaldehyde was largely responsible for the reported complaints. According to the hypersensitivity hypothesis (introduced in Section 6.2), somewhere between 0.5 percent and 2.0 percent of the population is sensitive to exposure to any concentration of formaldehyde. Assuming that the trait "formaldehyde hypersensitivity" is randomly distributed throughout the population, then one would expect that, in most cases, only one occupant per mobile home with formaldehyde problems would experience formaldehyde

Table 9-11. Minnesota: Symptoms Experienced by Mobile Home Occupants

Symptom	No (%)	Yes (%)	Persists Unknown (%)	Persists Yes (%)	Persists No (%)
eye irritation	35	65	64	2	33
nose & throat irritation	47	53	83	3	13
runny nose	56	44	88	4	7
cough	58	42	87	5	8
headache	60	40	87	2	11
frequent colds	65	35	97	1	2
diarrhea	66	34	93	1	6
cough-up	73	27	93	2	5
skin rash	74	26	96	3	2
shortness of breath	75	25	92	2	5
abdominal	76	24	94	2	4
increased urination	82	18	94	2	5
nausea	83	17	94	1	6
vomiting	85	15	96	1	3
chest pains	86	14	97	1	2
tired	98	2	100	0	0
dizzy	98	2	100	0	0
ear infections	99	1	100	0	0
asthma	99	1	100	0	0
pneumonia	99	1	100	0	0
sinus troubles	99	1	100	0	0
dry	100	0	100	0	0
passed out	100	0	100	0	0

Table 9-12. Minnesota: Number of Symptoms Reported by Mobile Home Occupants

Number of Symptoms	#	% of Sample	Cumulative %
11	17	5.2	5.2
6 - 10	106	32.1	37.3
5	50	15.2	52.5
4	39	11.8	64.3
3	42	12.7	77.0
2	26	7.9	84.9
1	26	7.9	92.8
None	24	7.3	100.1

Table 9-13. Minnesota: Percentage of Occupants Experiencing Selected Symptoms by Formaldehyde Level

Formaldehyde Level	Eye Irritation	Nose/Throat Irritation	Headaches	Frequent Colds
Less than .5 ppm	59%	48%	38%	38%
.51 - 1.0 ppm	71%	55%	38%	32%
1.01 - 1.6 ppm	75%	72%	56%	38%
1.61 - 2.0 ppm	91%	64%	45%	0%
Larger than 2.0 ppm	82%	55%	36%	18%

symptoms.* Table 9-14 displays the number of occupants reporting three or more formaldehyde symptoms for a given number of occupants in the mobile home.** In over 80 percent of the cases where at least one person has three or more formaldehyde symptoms, more than one person reported three or more symptoms. Indeed, in approximately half the cases all mobile home occupants reported experiencing three or more formaldehyde symptoms. These results are inconsistent with the (random population) hypersensitivity hypothesis, and unless a strong genetic linkage for formaldehyde sensitivity is insufficient to explain the distribution of reported complaints.

Although Minnesota has the most systematic reporting and sampling procedure of any of the three states, there still remain several limitations. First, the measurement technique utilized only one impinger for 30 minutes. Although the measurements were adjusted for 100 percent efficiency and are scientifically valid, the recommended NIOSH method was not employed. Second, it is unclear what proportion of Minnesota physicians have not been

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* More precisely, the probability, P, that exactly one mobile home occupant is hypersensitive, given that at least one occupant of the mobile home is hypersensitive, is

$$P = \frac{n(H)(1-H)^{n-1}}{1-(1-H)^{n}}$$

where H is the proportion of the population that is hypersensitive and n is the number of occupants in the mobile home. For H = 0.01 and a family size of four, the probability that exactly one occupant reports formaldehyde symptoms in a home with formaldehyde problems is approximately 0.98.

** Identical tests were run for occupants reporting two or more, four or more, and five or more symptoms. The results were similar to those reported here.

Table 9-14. Number of Family Members Experiencing Three or More Symptoms

FAMSIZE	PER3M 0.	1.	2.	3.	4.	5.	6.	ROW TOTAL
1.	1 20.0 10.0 0.9	4 80.0 21.1 3.7	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	5 4.6
2.	4 16.0 40.0 3.7	7 28.0 36.8 6.4	14 56.0 42.4 12.8	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	25 22.9
3.	4 8.5 40.0 3.7	8 17.0 42.1 7.3	16 34.0 48.5 14.7	19 40.4 76.0 17.4	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	47 43.1
4.	1 4.2 10.0 0.9	0 0.0 0.0 0.0	3 12.5 9.1 2.8	5 20.8 20.0 4.6	15 62.5 88.2 13.8	0 0.0 0.0 0.0	0 0.0 0.0 0.0	24 22.0
5.	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 14.3 4.0 0.9	2 28.6 11.8 1.8	4 57.1 100.0 3.7	0 0.0 0.0 0.0	7 6.4
6.	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 100.0 100.0 0.9	1 0.9
COLUMN TOTAL	10 9.2	19 17.4	33 30.3	25 22.9	17 15.6	4 3.7	1 0.9	109 100.0

Number of Family Members

informed of the Department of Health project and are therefore not referring their patients with formaldehyde symptoms to the Department.* A home is sampled only after its occupants have been referred by a physician; thus, to the extent a significant percentage of Minnesota physicians are not identifying and reporting cases with formaldehyde symptoms, the incidence of formaldehyde problems reported here will be significantly underestimated. Third, it is unclear what proportion of the mobile home population have failed to report formaldehyde symptoms to their physician. In an attempt to resolve this problem, the health department has sent out a public information brochure that discusses symptoms associated with formaldehyde exposure and their program. In an effort to reach as many mobile home owners as possible, the state health department sent the brochures to organizations and individuals that homeowners would most likely be in contact with: mobile home parks, dealers, manufacturers, and installers; local, county, and regional health departments; and Federal and state agencies, such as mobile home commissions, CPSC offices, and the consumer protection bureau of the attorney general's office.

9.4 SUMMARY OF THE MAGNITUDE OF THE FORMALDEHYDE PROBLEM IN MOBILE HOMES

All three samples (Washington, Wisconsin, and Minnesota) show similar results in certain categories of data. For instance, the number of

* The Department of Health project and formaldehyde issue were briefly discussed in a physician newsletter that is sent to all registered physicians within the state, but there is no way to tell how many physicians read them.

reported formaldehyde problems in all three states is strongly (negatively) correlated with the age of the mobile home. As demonstrated in Table 9-15, more than 59 percent of each sample were less than 2 years old. At least 83 percent of each sample reported formaldehyde levels below 1.0 ppm, and at least 50 percent of each sample reported concentrations below 0.4 ppm (Table 9-15). Finally, the symptoms reported most often in all three samples were eye irritation, respiratory irritation, and headaches.

Unfortunately, as indicated earlier in this section, a sample of formaldehyde complaints is available only for Washington, Wisconsin, and Minnesota. In addition to the methodological limitations in the sample procedures for each state, it is highly unlikely that the magnitude of formaldehyde complaints in these three (northern) states is representative of the Nation as a whole. In particular, the dense mobile home population in southern states, including Florida, California, and Texas, is not represented at all in this sample. Nevertheless, the data from Washington, Wisconsin, and Minnesota should provide some very rough estimate of the magnitude of the formaldehyde problem nationally.

If we combine the cases from all three samples, the total corresponds to 274 cases in the three states annually. Using the methodology developed by the U.S. Fire Administration, T+E estimates that there are 233,502 mobile homes in the three states at year-end 1979. Thus, approximately 0.1 percent of the mobile homes experience a formaldehyde problem. Furthermore, if we assume that the formaldehyde problems experienced in these three states are nationally representative, and using the U.S. Fire Administration estimate for the national stock of mobile homes of 4,145,230 at year-end 1979, then

Table 9-15. Comparison of the Mobile Homes in the Formaldehyde Data Base

	Washington	Wisconsin	Minnesota
% of mobile homes under 2 years old	59	80	61
% of mobile homes with formaldehyde levels below 1 ppm	94	85	83
% of mobile homes with formaldehyde level below 0.4 ppm	56	51	50
Average formaldehyde level in sampled mobile homes (ppm)	.64	.66	.61
Average formaldehyde level for mobile homes less than 2 years old (ppm)	.76	.71	.83

the number of mobile homes in the United States with formaldehyde problems each year is approximately 4,864. If we again assume that mobile homes have an expected life of 18 years, then each mobile home has a 2.1 percent chance of causing formaldehyde problems during its lifetime (see Table 9-16).

We should note that the Minnesota program to collect formaldehyde complaints and monitor formaldehyde levels in mobile homes is, in our view, by far the most systematic reporting and sampling program in the country. To date, they have made the strongest attempts to inform physicians and the mobile home population of their program. They also require physician referral before a complaint can be registered as such and, thus, before a home can be monitored. Therefore, we feel that the Minnesota sample is more representative of the actual magnitude of the formaldehyde problem occuring in a Minnesota home of a given age. Over its lifetime, the probability that the mobile home has a formaldehyde problem is 0.0377 (3.77 percent). Again, national extrapolations from these data must be heavily qualified; they represent only a very rough sketch of the potential formaldehyde problem in U.S. mobile homes (see Table 9-17).

Just as all three samples have some similar findings, they also have limitations that apply to each one. First, the sample mobile homes were not tested for the presence of other chemicals, such as carbon monoxide, benzene, and other substances, which might be responsible for or have contributed to the observed symptoms.* Second, each sample may not represent

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* However, Mary Ann Woodbury of the Wisconsin Department of Health and Social Services reports that in Wisconsin's sample, carbon monoxide levels were tested, and that a trained industrial hygienist had reason to suspect it. In no cases was carbon monoxide associated with eye irritation.

Table 9-16. Estimated Number of Mobile Homes Experiencing a Formaldehyde Problem

based on sample (s) from	cases reported	duration of sample	corresponds to x cases annually	USFA mobile home stock estimate '79	% of U.S.homes with formaldehyde problems each year	chance of each mobile home causing a formaldehyde problem in its lifetime
Washington, Wisconsin, and Minnesota combined	343	--	274	233,502	.12%	2.1%
Washington*	187	22 months	102	101,973	.10%	1.8%
Wisconsin**	47	21 months	27	63,136	.04%	.77%
Minnesota**	109	9 months	145	68,393	.21%	3.8%

* Occupant complaint
** Occupant complaint validated by a physician

Table 9-17. Minnesota: Probability of a Formaldehyde Problem by Age of Mobile Home

Age of Mobile Home	Probability (as a %)
≤ 1 year	1.87
1-2 years	1.00
2-3 years	.40
3-4 years	.20
4-5 years	.20
> 5 years	.10
	3.77%

its entire state. To the extent that this is true, the figures reported represent a lower bound on the magnitude of the problem. Third, at this point it is unclear whether the climate of each state is such as to overrepresent or underrepresent the frequency and level of formaldehyde outgassing nationally. Fourth, the months of the year during which each sample was conducted may not be representative because of climatic factors. Hence, a one-time air sample is unlikely to represent the true exposure of the occupants to formaldehyde over time. Finally, because people were asked to close up their homes (close all door and windows) for approximately 12 hours before the home was to be sampled (this is an attempt to show the "worst-case" scenario), the formaldehyde concentration readings taken reported and used for data are in many cases higher than the actual levels experienced most of the time by the occupants. This caveat indicates that many occupants feel adverse health effects and experience formaldehyde symptoms at levels significantly lower than those measured.

The primary conclusion to be drawn from these data is that a nonnegligible formaldehyde problem exists in Washington, Wisconsin, and Minnesota. For these three states, a mobile home has a lower bound of a 2 to 4 percent probability of experiencing a formaldehyde problem during its lifetime. A defensible estimate of the magnitude of the formaldehyde problem nationally is not possible at this time. What is required for such an estimate is a national sample of formaldehyde concentrations in mobile homes and a characterization of occupant formaldehyde symptoms associated with formaldehyde levels in the sample.

Appendix A

THE EUROPEAN EXPERIENCE

Appendix A

THE EUROPEAN EXPERIENCE

Formaldehyde, as it relates to the indoor environment, first attracted attention in Europe in 1974. Results from a first scientific study on indoor formaldehyde concentrations were publicized in three papers written jointly by Andersen, Lundquist and Molhave (1974a,b,c). In these papers, Andersen and his colleagues discussed reports of formaldehyde measurements in 23 Danish homes. They also assessed the release of formaldehyde from particleboard under controlled conditions in a climate chamber, and quantified the liberation of formaldehyde from particleboard with the development of a mathematical model. These works are summarized in English by Andersen et al. in an article in Atmospheric Environment entitled "Indoor Air Pollution Due to Chipboard Used as a Construction Material" (Andersen et al. 1975).

One hundred measurements of formaldehyde were taken in 25 rooms in 23 Danish dwellings. The houses were new or almost new (less than 5 years old) and contained varying quantities of particleboard. Formaldehyde levels averaged 0.62 mg/m^3 with a range from 0.08 to 2.24 mg/m^3. All of the values exceeded the West German MIK ambient standard of 0.03 mg/m^3. Values exceeded the calculated value for long-term exposure (0.04 mg/m^3) in some of the rooms sampled. Andersen and his colleagues presumed that at this value the inhabitants of the dwellings would experience adverse effects of the upper respiratory tract. Formaldehyde levels also exceeded the Danish TLV (threshold limit value) for exposure in workrooms (1.2 mg/m^3).

It was found that formaldehyde concentrations in the indoor air decreased with the increasing age of the building and with increasing rates of ventilation (Andersen et al. 1974a, 1975, 1979). In addition, Andersen, Lundquist and Molhave used a climate chamber to provide a controlled environment for measuring the release of formaldehyde from particleboard under climatic conditions corresponding to those which would occur in dwellings. At 22°C, 35 percent relative humidity, and an air exchange rate of 0.5 times per hour, release of formaldehyde from untreated particleboard was such that concentrations equilibrated at 0.8 mg/m^3, a level twice the value of the calculated level for long-term exposure. The rate of formaldehyde release increased with elevated temperatures and higher humidities. Formaldehyde concentrations, however, did not build up under conditions of increased ventilation. It was concluded that the rate of formaldehyde release depends upon the concentration of HCHO in the air surrounding the boards (Andersen et al. 1974b).

Using knowledge gained from these inquiries, a mathematical model was formulated to determine the equilibrium formaldehyde concentration in an atmosphere of known temperature, water vapor content, air exchange rate, volume, and surface area of particleboard. The model was tested in a climate chamber and calculated values compared with measured values by a correlation coefficient of 0.94. The model:

$$E = \frac{(RT + S)(ah + b)}{1 + \frac{nc}{\alpha}} \text{ mg HCHO/m}^3$$

E = formaldehyde vapor in the atmosphere (mg/m^3)

T = temperature (°C)

H = water vapor content (g H_2O/kg air)

n = ventilation rate (number of changes of air per hour)

α = particleboard content of room (m^2 boarding/m^3 room volume).

R, s, a, b, and c are constants determined from measurements in the climate chamber.

was adjusted to predict equilibrium values in dwellings.

In the adjusted model, the value of R is replaced by R_{corr}, calculated using the equation:

$$R_{corr} = \frac{1}{\bar{T}} \left\{ \frac{1 + \frac{\bar{n}c}{\alpha}}{a\bar{H} + b} \right\} (\bar{E} - S)$$

where $\bar{E}$, $\bar{T}$, $\bar{F}$, and $\bar{n}$ are average values for formaldehyde vapor (mg/m^3), temperature (°C), water vapor content (g H_2O/kg air), and ventilation rate (average number of changes of air per hour) respectively, calculated on the basis of 5-10 room measurements. Calculated values compared with measured values with a correlation coefficient of 0.88.

For the comparison of formaldehyde levels in different dwellings, it was recommended that standard conditions of 23°C, 40 percent relative humidity, and 1.0 air changes per hour be used for the indoor environment. Additionally, it was recommended that restrictions be placed on the amount of particleboard used in dwellings, especially in rooms with high temperature, high humdity, and poor ventilation. The implementation of those restrictions would depend in part upon the development of surface treatments and changes in the inner physical-chemical characteristics of the board (Andersen et al. 1974c). As a result of these studies, Danish chipboard producers

changed their production method. A followup investigation of homes with new types of chipboard measured formaldehyde concentrations at about 0.30 mg/m^3, about 50 percent lower than the 1973 value.

Swedish homeowners, in 1975, reported symptoms of eye irritation and headaches to health officials. Health inspectors, using Draeger multi-gas analyzers, measured formaldehyde at levels from 1 to 7 ppm. Measurements using the more accurate chromotropic acid method indicated the real formaldehyde concentrations to be between 0.7 and 1.2 ppm. Results of the Draeger analysis were reported to the press, resulting in a flood of complaints from homeowners of houses less than 1 year old, built using particleboard for floors and/or walls. The content of free formaldehyde in particleboard, however, measured using the European Federation of Association of Particleboard Manufacturers' Perforated Method, decreased from 1970 to 1975 (Sundin 1978).

Following these findings, Andersen and his colleagues designed a chamber study "to study the effects of five hour exposures to 0.3, 0.5, 1.0 and 2.0 mg formaldehyde/m^3." Sixteen healthy young adults were exposed to HCHO levels under well-controlled conditions. Several physiological parameters were measured, as well as subjective discomfort and performance. Complaints of conjunctival irritation and dryness in the nose and throat were registered. The number of complaints increased with increased exposure. Only slight discomfort was reported. The performance of the subjects was the same at all conditions. These studies led to a proposed standard value of 0.15 mg/m^3.

The European indoor formaldehyde standards, promulgated or proposed, (see Section on Standards) were essentially based on the Andersen studies. The emphasis of these scientific endeavors, and other parallel European works, has been on indoor formaldehyde concentrations. The standard(s) were set at a level tract that "...would protect all but sensitized subjects from adverse health effects" (Andersen 1979). The literature does not explicitly state enforcement means, but it does indicate that the board manufacturing industry is responsible for reducing the emission rates. Although compliance is not universal, Danish scientists feel that the current formaldehyde problem is substantially less than in the mid-70's. They see a cause-and-effect relationship between the scientific studies, the consumer complaints and the proposed indoor standards. Indirect communications with representatives of the Danish board industry attribute the reduced formaldehyde emissions to "improved manufacturing technology" without further details.

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Appendix B

AUTHOR INDEX

Appendix B

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7.0 FORMALDEHYDE STANDARDS

Andersen, I.
American Conference of Governmental Industrial Hygienists
American Industrial Hygiene Association
Cleveland, W.S.
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Hollowell, C.D.
International Labour Office, Geneva
Lindval, T.
McFadden, J.E.
Melekhina, V.P.
National Academy of Sciences
Naval Sea Systems Command
Roffael, E.
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United States of America Standards Institute
U.S. Department of Health, Education, and Welfare
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8.0 ABATEMENT TECHNIQUES

American Society of Heating, Refrigerating and Air Conditioning Engineers
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Bruce, R.W.
Chalmin, A.
Diaper, E.W.J.
Hanetho, P.
Hardwood Plywood Manufacturers Association
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White, J.T.

9.0 THE MAGNITUDE OF THE FORMALDEHYDE PROBLEM

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